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The 600,000-LB.
Testing Machine
For the Laboratory
Of Applied Mechanics

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THE 600,000-LB. TESTING MACHINE
FOR THE
LABORATORY OF APPLIED MECHANICS

BY

FRANK ALFRED RANDALL

THESIS

FOR

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IN

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This is to certify that the following thesis prepared
under the direction of Professor A. N. Talbot, Head of the De-
partment of Municipal and Sanitary Engineering, by

FRANK ALFRED RANDALL

entitled THE 600,000-POUND TESTING MACHINE OF THE LABORATORY
OF APPLIED MECHANICS

is hereby approved by me as fulfilling this part of the require-
ments for the Degree of Bachelor of Science in Civil Engineering

Ira O. Baker.

Head of Department of Civil Engineering



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RIEHL U. S. STANDARD VERTICAL SCREW POWER TESTING MACHINE WITH DIAL SCREW BEAM.

600,000 LBS. (300,000 KILOS). "TALBOT."

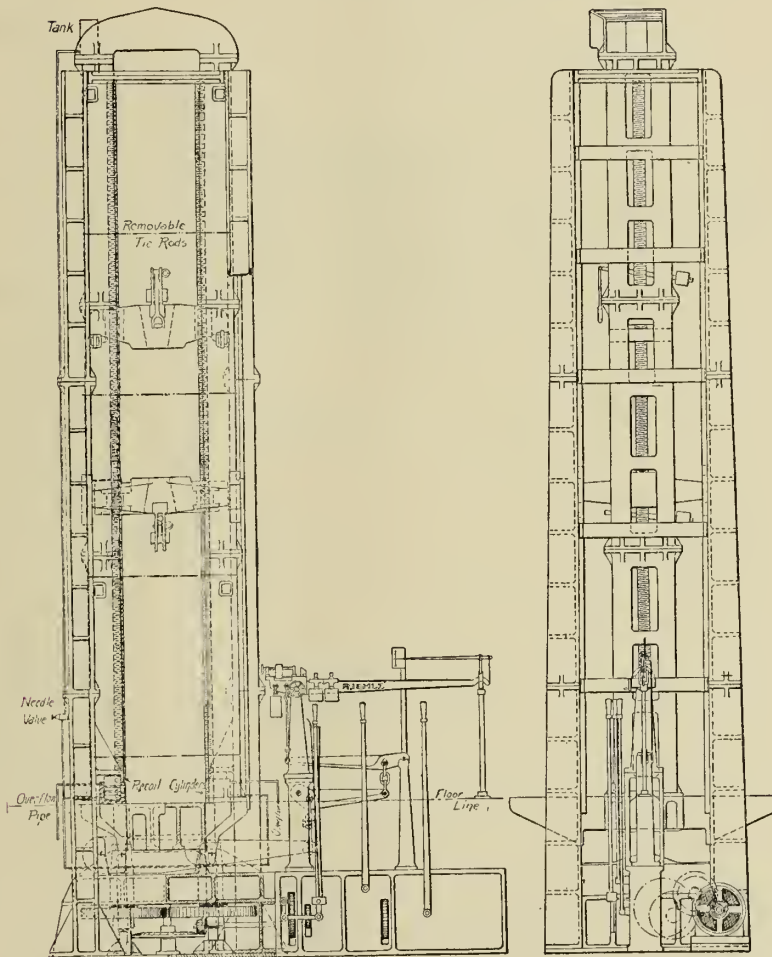


Fig. 1.

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INTRODUCTION.

The 600,000 pound testing machine in the Laboratory of Applied Mechanics of the University of Illinois which is discussed in this thesis is peculiar in several respects, notably in its design and its capacity. The design is characterized by certain distinctive features which are not common to other machines, while in point of capacity and in size of specimen that can be accommodated, it is exceeded by no other vertical screw power testing machine in the world.

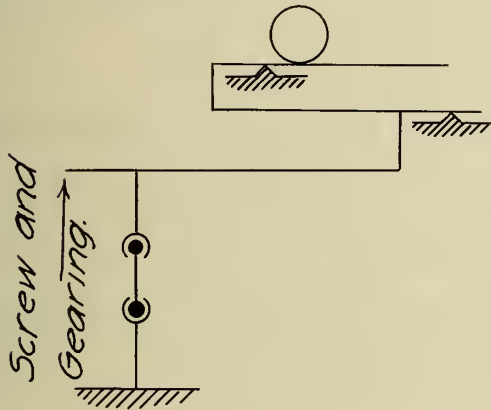
These facts make its study doubly interesting. The various types of testing machines will be discussed, a description will be given of this particular machine, its design will be investigated, and the calibration and other tests upon which it was accepted will be given.

I.

HISTORICAL.

Although the history of testing machines in this country does not go back more than fifty years, it is within the last twenty-five or thirty years that the greatest advance has been made in their development and use.

Major Wade built a machine in 1855 and 1856 for government ordinance service, which was one of the first testing machines



in this country. The machine consisted of a frame and three levers, the smaller of which was used as a scale beam. The test piece was fastened to the frame and largest lever, the scale system being raised by a screw and gearing. The amount of stress was determined by balancing weights on the scale beam.

This machine was designed to take but small specimens and was soon followed by the first machine designed to take full sized rods as test pieces.

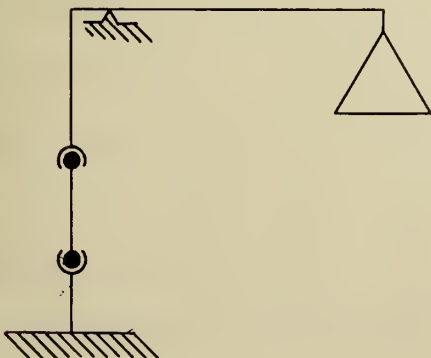
Very little more was done until after the war when a large machine was built for Colts Armory by Fairbanks and Company. The capacity was 50 T and this was the first platform testing machine built. The straining head was operated by means of an hydraulic jack, the stress being carried by a system of levers to a scale beam where it was balanced with weights. One of the first testing machines built by a scale manufacturer was built in 1867 by the firm of Banks, Dinsmore and Company, Philadelphia, of which Mr.

Riehle was a member. This machine was followed by others and much interest was awakened in the subject, so much so that at a convention of the American Society of Civil Engineers held at Chicago in 1872 a committee was appointed to urge upon the government the necessity for a thorough series of tests of American iron and steel. The purpose of the committee was achieved and in 1879 the celebrated Emery machine at the United States Arsenal at Watertown, Massachusetts, was finished. This has a capacity of 500² T and is capable of testing specimens up to 30 feet in length both in tension and compression and will be described later.

What is thought to be the first machine autographically recording the results of tests in other than tension was constructed in 1877 by Abbott. Prof. Thurston had built one shortly before this for torsion. Abbott's machine had a capacity of 50 T, the length of specimen being limited to 2 feet.

Since 1880 great improvements have been made in testing machines, new types such as the Olsen and Riehle have been introduced and the matter has reached a high state of development. These types will be discussed later.

In Europe the development was along similar lines, the principal difference being in the manner of applying the stress.



After the primary stage in which the specimen was anchored to a foundation at one end and pulled at the other by the short end of a lever balanced with weights hydraulic power came into use and is used quite extensively as contrasted against the use of screws and gearing in the United States.

Mr. Tinius Olsen, who is probably one of the foremost pioneer testing machine men of this country was asked if he would tell something of his early connection with the industry and we take what follows from the notes which he very kindly furnished:-

"In 1870 while employed as a draftsman by the William Sellers Company designing tools, I had become socially acquainted with the Riehle Brothers who had just shortly before this bought out a small business for manufacturing scales. About this time some makers of boiler plates had asked them if they could make a testing machine for them for the purpose of testing the plates. I was then asked what I knew of testing machines and if I could design one.

"On this my first drawing for a testing machine was made, being a simple application of one then well known weighing apparatus consisting of a crane beam to one end of the specimen and a hydraulic jack to the other, with proper tools for securing the ends of the specimens.

"At a later date a larger machine was desired by the Pennsylvania Railroad Company and I made a new design for this. The execution of this drawing was rather too much for Riehle Brothers shops' knowledge at that time and I was much called upon to guide the work of these machines. This led them to desire me to accept the position of superintendent of their works which I did at the beginning of the year 1872.

"In the following eight years I made many new designs, and many new patents were taken out, especially in 1879, which were all assigned to Riehle Brothers." On account of some trouble over

patents Mr. Olsen left Riehle Brothers about this time. To quote again from the same source:-

"During the past years Fairbanks Company also had made some testing machinery, mainly by applying strain mechanism to their existing scales.

"Having for so many years put my whole attention to testing machines and scales, and feeling that more was to be developed in that line, I set to work and designed a new type of machine, the screw machine, all previous had been hydraulic, which was patented June 1, 1880. This design in a short time superseded all previous designs and is the basis of all vertical designs and forms as made today in this country.

"Fairbanks at once ordered three of these machines to sell to prospective customers with the understanding that I should take charge of this business for them but being unable to effect satisfactory business arrangements, I started my own place of business April 1, 1881.

"The first testing machine designed for a technical institution was for the Stevens Institute of Technology, Hoboken, N. Y., and ordered by the late Doctor Thurston in 1894."

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II.

TYPES OF MACHINES.

After the preceding brief history of the introduction of testing machines, their classification will be discussed.

There are four general classes with subdivisions as follows:--

1. As to Use.
 - (a) General
 - (b) Specific
2. As to Position of Specimen.
 - (a) Vertical
 - (b) Horizontal
3. As to Method of Application of Stress.
 - (a) Screw
 - (b) Hydraulic
4. As to Method of Measuring Stress.
 - (a) Knife Edge Lever
 - (b) Hydraulic Lever
 - (c) Hydraulic or Mercury Gauge

These classes will now be discussed in brief and examples given of each.

1.(a) General testing machines are those designed to make experiments in three or four different ways, as for example, in tension, compression, transverse stress, shear, bulging, punching, abrasion, impact, denting or torsion. Most general machines are limited to the first three or four of these although the Kirkaldy machine, one of the largest in use, was designed for testing in tension, compression, bending, shearing, bulging and torsion. The subject of this thesis is also an example of a machine designed for general uses. These machines are sometimes called universal machines.

(b) Special machines are those limited to one particular form of test, as for examples, machines for testing wires, concrete in tension, springs, chains, etc., or machines limited to tension, compression, torsion, etc. While many of this class are of but small capacity, some large machines may be cited as examples, notably the large machine at the Pencoyd Plant, American Bridge Co. at Pencoyd, Pa., which is limited to tests in tension and the machine at the Keystone Bridge Works, Pittsburg, Pa.

2. Vertical and horizontal machines are so called from the position of the specimen. The advantages and disadvantages of both will be discussed further on.

(a) The vertical machines generally have the pulling head operated by screws and gearing and have the stresses measured by levers and weights. The Olsen and Riehle types of machine to be described later on are examples of this style of machine.

(b) The horizontal machine is the characteristic type for the larger machines operated by hydraulic power and for the present Emery machine. The largest machine in the world, that of the Phoenix Iron Co., Phoenixville, Pa., is of this class, i.e. horizontal.

3. (a) As was indicated in (2), screw machines are used in great part with the vertical type and hydraulic power with the horizontal type of machines almost without exception. Screws and knife edge levers are generally used with machines designed for experimental work and other uses which require higher refinement and also, of course, for commercial testing while hydraulic power combined with hydraulic gauge is used for commercial and such other work as does not require extreme accuracy. The Riehle and Olsen are screw machines while the Kirkaldy and Buckton-Wicksteed use hydraulic power. Screw and gearing is the favorite type in America

and the hydraulic jack in Europe.

4. Probably as important as any classification is the classification according to the manner in which the stress is measured.

(a) The knife edge lever method is the most common. In this the load upon straining head is communicated by means of knife edges and a system of one or more levers, to a scale beam upon which the stress is measured by means of a movable balancing weight. All lever machines except the Emery machine are of this type.

(b) The method for which the greatest accuracy is claimed is the hydraulic lever method which is characteristic of the Emery machine. The weighing device is a flat cylinder called an hydraulic support. The pressure is conveyed from this cylinder to a smaller cylinder which operates the weighing levers. These levers are not balanced upon knife edges but are connected by flexible steel plates or "platen" designed so that the stress does not exceed elastic limit and reducing the losses due to friction to practically nothing.

(c) The crudest and one of the first methods used to measure the stress was by means of an hydraulic gauge which indicated the unit pressure at base of hydraulic jack, from which was easily computed the total stress.

III.

EXAMPLES OF EXISTING MACHINES.

The following machines will be described:

1. General types.
 - (a) Riehle
 - (b) Olsen
 - (c) Emery
 - (d) Buckton-Wicksted
 - (e) Werder
2. Special or particular machines.
 - (a) Watertown
 - (b) Athens, now Pencoyd
 - (c) Phoenix

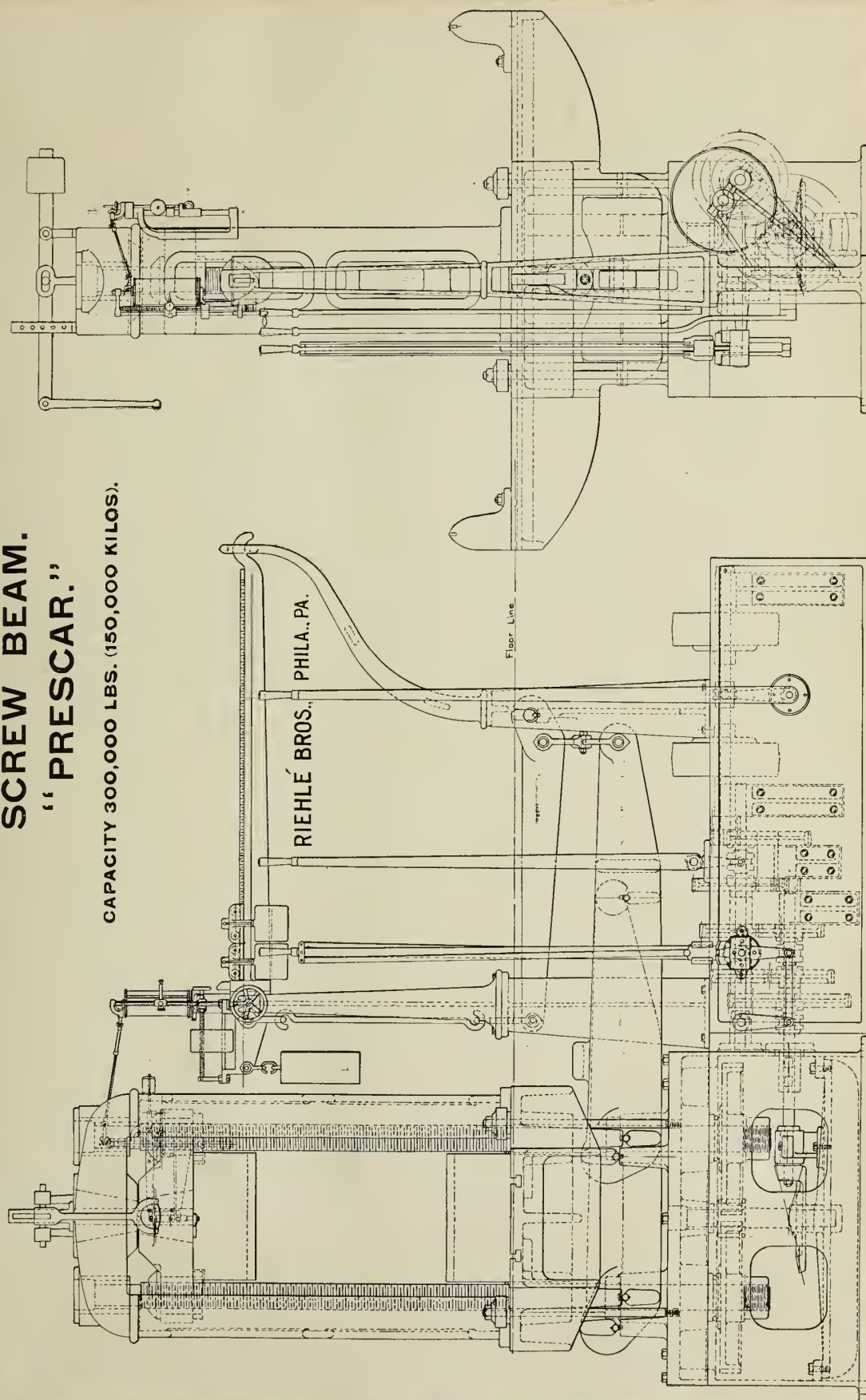
1.(a) The Riehle machine is manufactured by Riehle Brothers Testing Machine Company, Philadelphia, Pa. They manufacture horizontal hydraulic power machines with capacities up to 800,000 pounds or more, vertical screw power machines with capacities up to 600,000 pounds and various smaller ones for particular purposes. The characteristic machine is the vertical screw power of 100,000 pounds to 400,000 pounds capacity. The following description is taken in part from their catalogue:-

"The top head of the machine, of cast steel, is supported by two cast iron columns which rest on the weighing table. This table in turn rests upon eight hardened steel knife edges in the main levers, these levers being held up by cast iron columns rising from the cover plate. Beneath this is the cast iron box containing the main gears.

"Through holes in the table two pulling screws pass up and reach nearly to the top head, running through pulling head which is raised or lowered according to which direction screws revolve." For tension the specimen is held in grips in top and pulling heads.

**RIEHLÉ U. S. STANDARD TESTING MACHINE, WITH DIAL
SCREW BEAM.
"PRESCAR."**

CAPACITY 300,000 LBS. (150,000 KILOS).



For compression, the specimen is placed between tools on lower side of pulling head and on weighing table. For transverse tests the specimen rests upon two tools on weighing table and load is applied through another tool on under side of pulling head.

"The weighing table rests wholly upon the main levers, the recoil bolts passing through it loosely. There are two main levers the one inside the other and of nearly equal length. Each of the levers branch into a Y under table to spread the points of support and to allow screws to pass into box. The knife edges are in direct line with pulling screws to insure an even distribution of load.

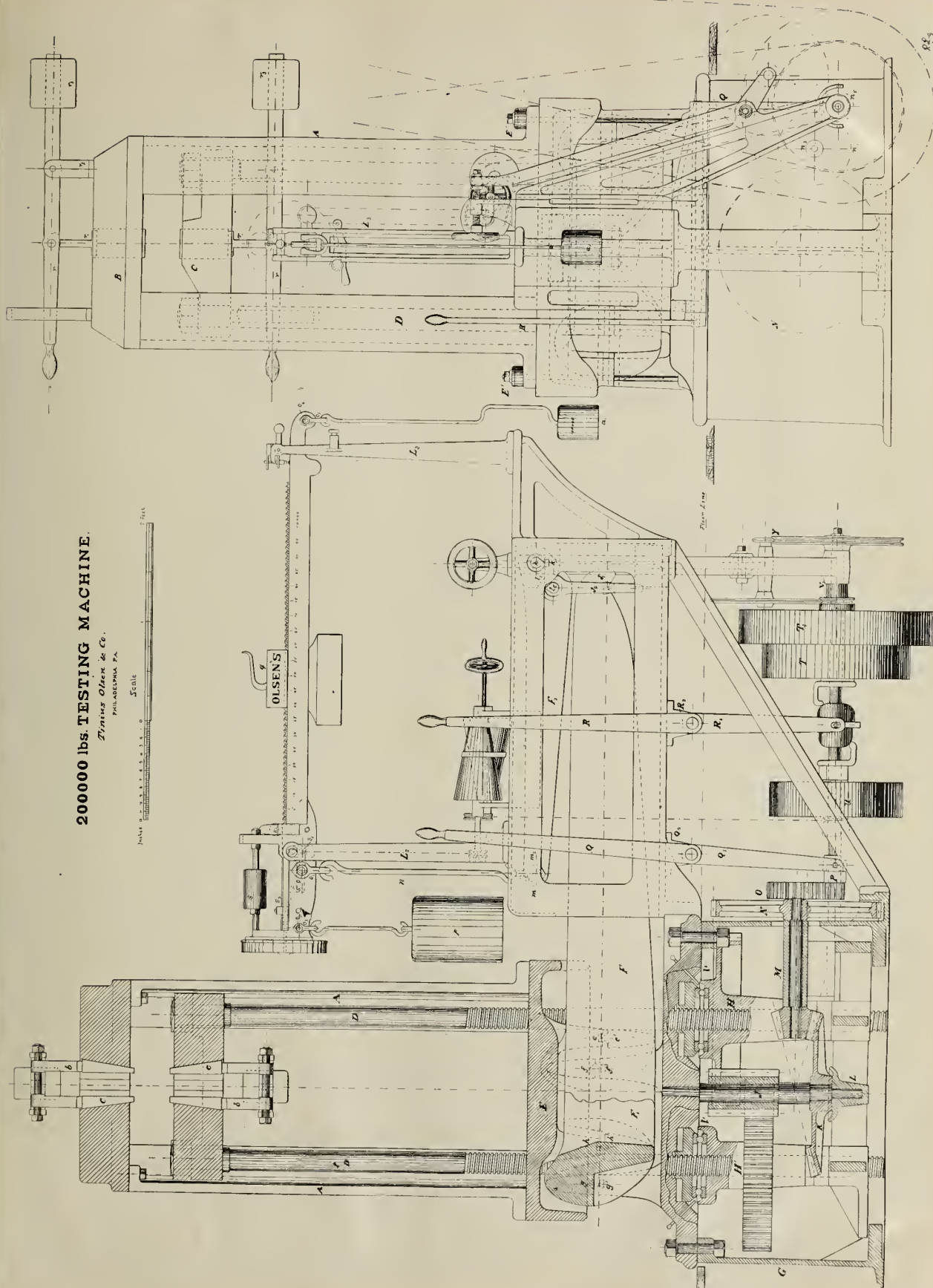
"The two pulling screws pass down through bearings in cover plate and to their lower ends are keyed the main gears." The machine is generally furnished with six pulling and six reversing speeds ranging from eight inches per minute to one-tenth inches per minute.

The machine can be provided with the Riehle automatic apparatus for operating the poise and the Riehle autographic apparatus for recording the stress and strain of test specimen.

(b) The Olsen machine is manufactured by Tinius Olsen and Company, Philadelphia, Pa. This machine differs very slightly in general design from the Riehle machine. The chief difference is that the Olsen machine has four straining screws and four weighing columns where the Riehle has but two. This difference carries with it a difference in the lever system also. The main lever system consists of three levers. The longest one receives the load from the rear set of screws, being divided at the "heavy" end into branches which are supported upon knife edges as nearly

200000 lbs. TESTING MACHINE.

Timms Olsen & Co.
PHILADELPHIA, PA.



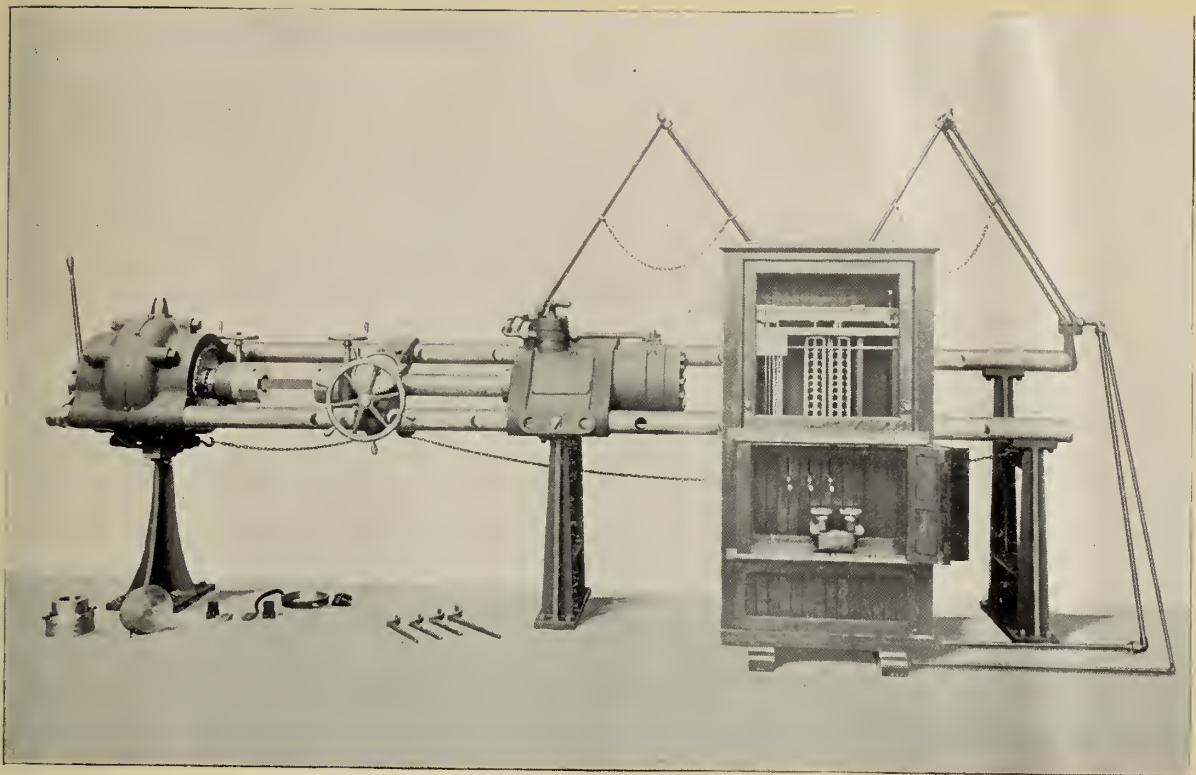
under screws as possible. The shorter levers run to the front screws and are outside of the long lever.

Under the bed plate is a collar and on the screws below this collar are nuts carrying a large gear wheel. These four wheels mesh with another but smaller gear wheel or pinion which is located in the center of the machine and is turned through trains of gears from the driving shaft.

(c) The Emery testing machine is peculiar in the method of measuring the stress. This is done in a way, which, it is claimed, is entirely frictionless. The general scheme is indicated in the figure on next page. The load is received upon the hydraulic support A and communicated through e to a second hydraulic cylinder B smaller than the first. bb are plates holding oil in cylinder and c is piston which is prevented from lateral motion by the plates dd. As the greatest motion under full load is not over 0.003 inches it is seen there is no friction other than that of the fluid.

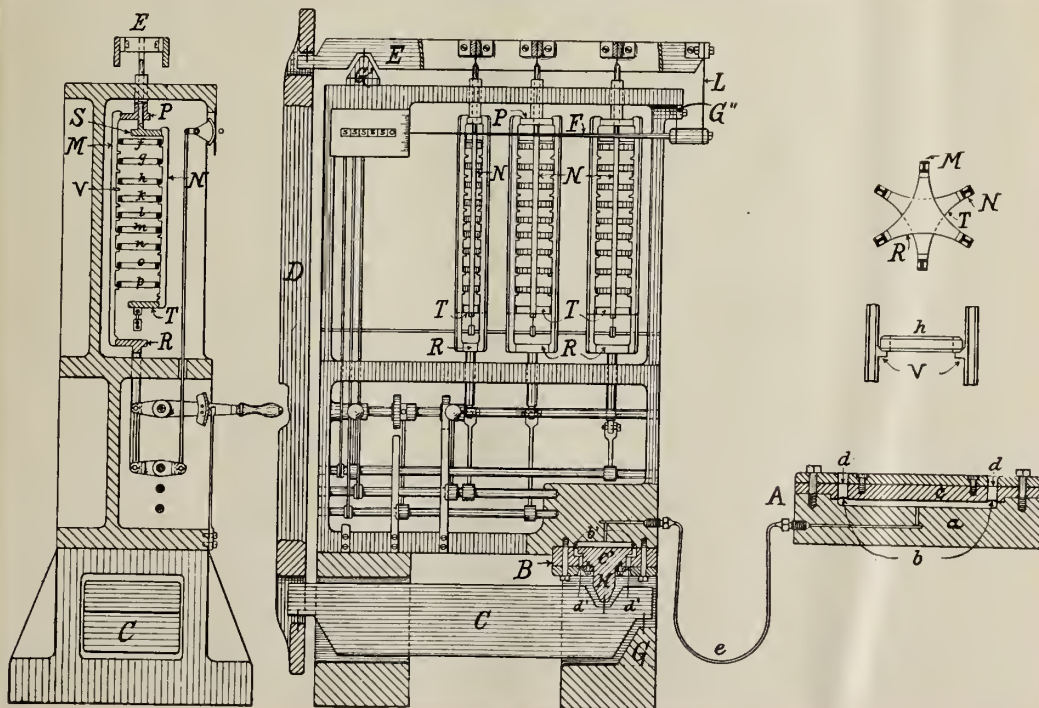
The piston c of the second chamber acts upon the lever C through H and from C the load is communicated to the lever E where it is balanced by means of the weights h. All supports and connections are thin plates instead of knife edges, the plates being of such length that the metal is not stressed beyond elastic limit and deterioration does not take place as soon as with knife edges.

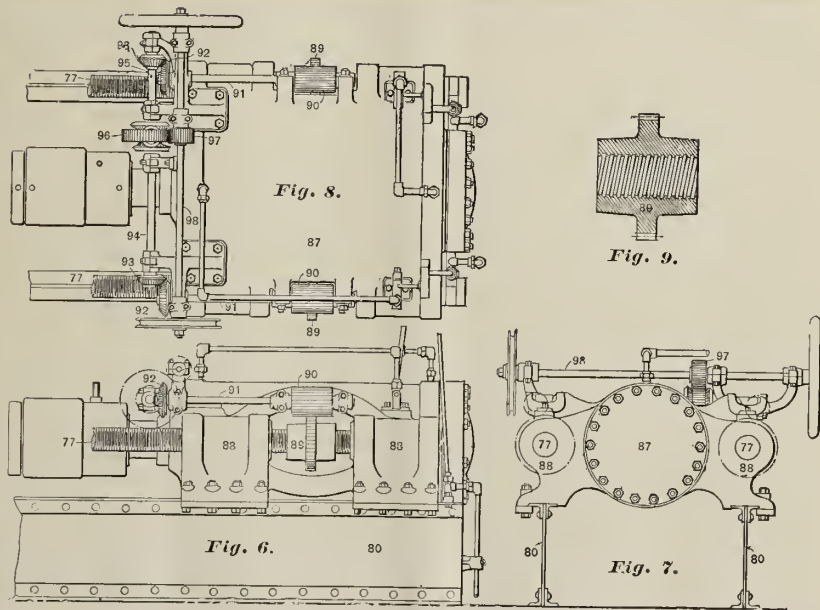
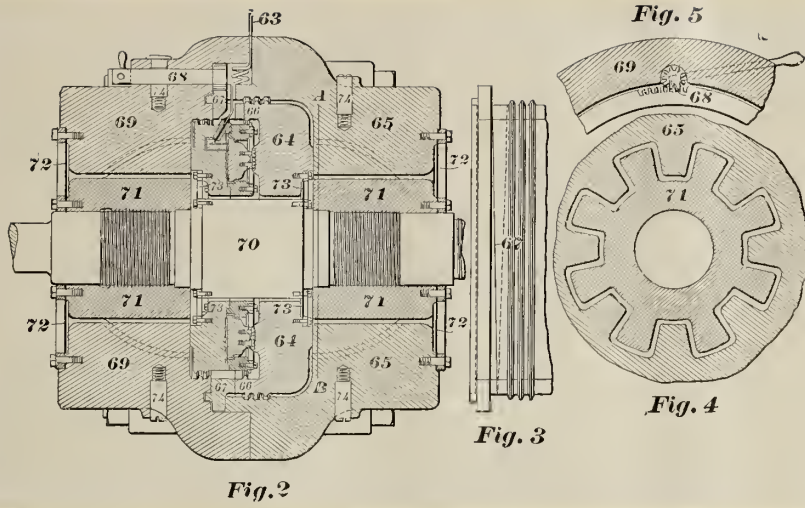
The scale is enclosed in a glass case and the scale weights are added in succession by the movement of a mechanical device, which raises and lowers the "weight frame" m thus subtracting or adding more weights upon "poise frame" n.



100,000 LB. EMERY TESTING MACHINE.

FIG. 1.





The last lever of the series is the indicator needle F which with a movement of $1 \frac{3}{4}$ inches to 2 inches at its point multiplies the movement of the piston "c" 300,000 to 6,000,000 times depending on the size of the machine.

The weighing head consists of two annular beams 65 (see figure) bolted together and containing the draw bar 70 along their axis. This drawbar is centered with respect to the beams by means of the plates 72 and centers the hydraulic support by plates 73, attached to the drawbar are the collars 71 provided with ribs as shown in Fig. 4. The end of the drawbar projecting at right in figure is threaded to receive tension and compression tools. When the specimen is in compression the collar 71 presses against the piece 64 which rests upon the hydraulic support, the latter bearing upon the ribs of the annular beam 69.

The shock due to recoil is reduced to minimum by bringing the beams 65 and 69 as close together as possible by means of the pinion shaft 68 (Fig. 5), thus reducing the motion and impact of recoil.

The straining head can be moved to desired position along two screws. These screws are attached to the weighing head and pass loosely through rotary nuts in the straining head 87 (Fig. 6, 7, 8), motion being communicated to the nuts 89 through a train of gears.

"The Emery testing machines are now made horizontal instead of vertical; in the first place to make all sizes of machines of one type, and in the second place to get certain advantages in overcoming the shocks of recoil. In all but the very smallest size of machines the weighing head and the hydraulic cylinder or

straining head are carried by the top surface of a wrought-iron bed."

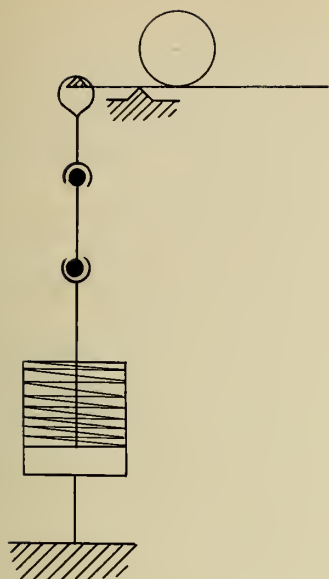
The largest Emery machine in use is the one already referred to at the Watertown Arsenal which is remarkable for its delicacy and precision. "It can break a hair and a bar of steel thirty feet long and the relative error in measuring the ultimate strength will be closely equal in the two cases." (Merriman and Jacoby-"Bridge Design").

(d) The Buckton-Wicksted machine is manufactured by Messrs. Buckton of Leeds, England, under a design of Mr. Hartley Wicksteed.

This is a single lever machine consisting of ^a cast iron upright with a "horn" at the top projecting back and carrying the knife edge which supports the main lever. This lever consists of two side plates separated for the greater part of their length but connected at their ends and at intermediate points. Upon the scale beam runs the jockey weight which weighs a ton in the 100 T machine. The weight is moved by means of a worm gear operated by a hand wheel.

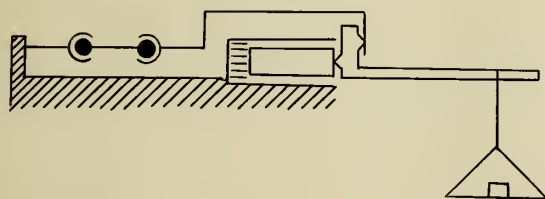
Suspended over a second knife edge carried by the lever is the tension grip, the leverage being four inches in the 100 T machine, thus adding a load of 1 T for every four inches the weight moves out along the beam. The beam is 200 inches long and when the weight reaches the end of its travel the load of 50 T is held by means of a counter weight and the poise returned and run out a second time.

The elongation of the specimen and its slip in the grips are taken up by an hydraulic press run by means of screws and gearing.



The figure illustrates diagrammatically the machine. Only short specimens can be tested.

(e) The Werder machine is also a single lever machine, represented diagrammatically in the accompanying figure. It is a



horizontal machine whose chief characteristics are its high leverage ratio and the fact that the weighing and straining apparatus are at the same end of specimen. This last device makes it possible to extend

the machine considerably without great increase in cost. The usual length of test specimen both in tension and compression is thirty feet. What follows applies more particularly to the 100 T machine which, however, possesses the common characteristics of all Werder machines.

The rear cross head is rigidly connected to the frame by

pieces which can be adjusted to fit the length of specimen. The front cross head or straining head, is connected by rods to a cross head resting against a knife edge upon the hydraulic ram.

The large horizontal lever is supported at the end of the ram with its fulcum 4 millimeters or about $3/16$ inches from the knife edge of the straining head. The length of the lever arm being 2000 millimeters the leverage is 500 so that the load required in scale pan at end of lever is but 448 pounds.

As the specimen elongates under the load applied, the lever tends to fall which would destroy the horizontal leverage. To take care of this the ram is provided, which being forced out as load increases, brings lever back to horizontal position, this being determined by level upon lever.

In compression the specimen, if short, is placed between straining head and rear end of press; if long, rods are extended to far cross head and specimen placed between this cross head and the straining head in tension.

Great precision is claimed for this machine and Professor Unwin in his "Testing of Materials of Construction" (1888) says "Probably it is not too much to say that by far the largest part of the original investigations carried out in the last fifteen years have been accomplished by the aid of Werder machines. In the hands especially of Dr. Bauschinger, of Munich, tests of materials have been made with this machine with a precision and accuracy never before obtained."

2.(a) The United States Government testing machine at the Watertown(Mass.) Arsenal is an hydraulic, horizontal machine of the Emery type, which has been described before. This machine

was designed for a capacity of 800,000 pounds in compression and tension but at the present time is not used for loads over 600,000 pounds. It is capable of taking specimens up to thirty feet in length and in compression by a "slight modification of its parts" can be adapted to specimens thirty-one feet eleven inches in length and in tension on eye bars to a length of thirty-seven feet three inches center to center of eyes. As was stated before, this is the first large testing machine in the United States and was built to meet the demand which existed for an extensive series of tests on American steel and iron.

The machine embodies the distinctive features of the Emery type. It consists of two heads, the straining press and the hydraulic scale, between which the specimen is placed. The press has a cylinder twenty inches in diameter with a stroke of twenty-four inches. The two heads are connected by two screws 8.5 inches in diameter and 48 feet long. The cylinder is moved along these screws by means of nuts driven by a central shaft. In this way the machine is adjusted for specimens of different length.

Among the specifications which were all successfully met were the following:-

First.- A machine with a capacity in tension or compression of 800,000 pounds with a delicacy sufficient to accurately register the stress required to break a single horse hair.

Second.- The machine should have the capacity of seizing and giving the necessary strains from the minutest to the greatest, without a large number of special appliances, and without special adjustments for the different sizes.

Third.- The machine should be able to give the stresses and receive the shocks of recoil produced by rupture of the specimen without injury. The recoil from the breaking of a specimen which strains the machine to full capacity may amount to 800,000 pounds, instantly applied. The machine must bear this load in such a manner as to be sensitive to a load of a single pound placed upon it, without adjustment, the next moment.

The extreme sensitiveness and the accuracy of this machine have been spoken of elsewhere.

(b) The 600 T. testing machine at the works of the American Bridge Company, Pencoyd, Pa., formerly at the works of the Union Bridge Company, Athens, Pa.

Before this machine was built there was but one large testing machine in America, that of the United States Arsenal at Watertown, which was capable of testing full size bridge members to destruction. This latter machine, also, was unable to turn out work excepting at the expense of considerable delay in time on account of the quantity of work required of it and hence the demand for another machine which could be controlled by private parties was very great.

The machine in general is of almost exactly the same design as that of the Phoenix machine, described later, the latter being copied from the former. It consists, as does the Phoenix machine, of:- a hydraulic cylinder securely fastened between two longitudinal girders, which form the frame of the machine; a tail block which may be attached to the webs of the girders at convenient intervals; and two connecting blocks to receive the test

pieces, attached respectively to the piston of the cylinder and the tail block. These blocks are carried upon finished wheels running upon an accurately finished and lined track upon the lower flanges of the girders. In this respect they differ from the Phoenix machine in which these blocks slide upon guide rods bolted to the girders.

The cylinder is of cast steel 4 feet 3 3/4 inches in diameter and 6 feet 1/2 inches long with an effective area of 2039 square inches and a working stroke of 4 feet 11 inches. The maximum water pressure for which provision is made is 600 pounds per square inch making a total strain upon test piece 1,223,400 pounds. The total friction of the machine has been measured as less than 4000 pounds when pressure is off. It is believed that when pressure is on and film of water is escaping that friction is greatly reduced. The main girders are of wrought iron 60 feet long by 3 feet 5 5/8 inches high. Holes are bored through the webs 6 1/2 inches in diameter and 18 inches center to center for attachment of tail block. The girders rest on twelve inch cross girders bolted to masonry foundation.

The tail block is a steel casting attached by pins to girder and having a connecting block attached to it by four steel rods.

The remainder of the machine is essentially the same, in form, as the Phoenix machine to be described later.

The length of specimen that can be tested is forty feet with an elongation of twelve percent.

(c) The 1200 T testing machine of the Phoenix Iron Com-

pany, Phoenixville, Pa.

This large and powerful machine was built to test to destruction full sized specimens of the largest members used for tension and compression in structural iron and steel work.

It is a modification of the machine formerly at Athens just described, the principal changes being that the head block runs on guide rods attached to the main girders instead of upon wheels and that the cylinder has been changed so that tests can be made in compression as well as in tension.

The double acting cylinder is 7 feet 10 inches long, 64 1/10 inches in diameter, has a stroke of 6 feet and weighs 10T and is bolted to the main girders by turned steel bolts 2 inches in diameter. The piston rods, four in number, are 8 1/2 inches in diameter making net area of cylinder 3000 square inches for tension. The piston rods and piston have brass glands for packing. The same number and size of rods are used at tail block. 9 1/2 inch stop pins, two in each girder, hold tail block in position.

The recoil and head blocks are provided with 10 inch pin holes which will receive eyes 30 inches in diameter and 4 1/2 inches in thickness.

The main girders are I's 78 feet long, 51 1/2 inches deep, and weigh 60 T. Each has a gross area of 244 1/2 square inches with net section at pin holes of 166 square inches. The anchor pin holes for tail block are 9.56 inches in diameter with 18 inch centers lengthwise and 24 inch centers crosswise. Two inch holes between pin holes crosswise are for convenience in removing pins

from ends of test piece. The girders rest on transverse plate girders and are stiffened by riveted gusset brackets. The machine will take an eye bar 50 feet long.

The machine has been intended for loads up to 2,160,000 pounds or a pressure of 720 pounds per square inch upon piston but it can be worked safely at pressure of 800 pounds per square inch upon piston or total load of 2,400,000. Although the diameter of piston is exceeded by those of many low pressure cylinders for steam engines, yet when fully loaded it is thought to carry more than any other piston ever constructed.

The packing of piston is different from that ordinarily used in hydraulic work. Brass glands surround the piston and rods confining several rings of ordinary flax packing. As pressure increases the flax is compressed and a thin film of water escapes around circumference, thus reducing friction as pressure increases. This friction has been measured on the Athens machine as was noted.

To make a test, the tail block is rolled along until it is opposite the pair of holes nearest right for the length of eye bar to be tested. Pins are then inserted in tail block and recoil block is adjusted to exact length of bar. Bar is then put in, stress applied, and readings taken on hydraulic gauge.

The Phoenix machine has been calibrated by means of comparative tests on the Emery machine at Watertown. The error was found to be about 15 percent.* The specimens were full sized columns, the test being in the interest of the City of New York.

See Engineering News of Oct. 7 1909 for latest tests showing much less error. H. F. M.

IV.

RELATIVE MERITS AS TO TYPES, SIZES, AND USES.

In comparing one machine with another it is necessary that there be a definite basis of comparison, for one machine will possess certain advantages for one particular kind of work while it may be almost completely useless or unadapted for another kind of work.

However there are certain qualities to be sought after in the design of all machines and prominent among these are the following:-

1. Sensitiveness
2. Accuracy
3. Adaptability
4. Convenience of Manipulation
5. Simplicity

1. For a machine to possess sensitiveness it must be so that it will indicate sharply small increments of stress. The sensitiveness depends upon the condition of the knife edges, the platen, on the amount of the hydraulic friction. Most machines, especially while new, are amply sensitive. Unwin says that a good 100 T machine will be moved distinctly by an addition of a stress of $1/100$ T, or a sensitiveness of $1/10,000$ or $1/100$ of one percent.

A sensitiveness of $1/10$ to $1/4$ of one percent would be amply sufficient for ordinary testing and still less is quite enough for the rougher and commercial tests. For excessive sensitiveness, the Emery machine stands first. It is claimed that

a weight of 200 grains laid on the platform of an Emery machine of 500,000 pounds capacity was sufficient to move the indicator needle 0.02 inches thus actually setting in motion material weighing more than 25,000 pounds. Of an Emery machine exhibited at Paris, it is reported that a horse hair was broken under a load of 16 ounces after breaking a specimen at load of 90,000 pounds. The Watertown machine, before being accepted, broke a link of hard iron five inches in diameter at a load of 722,000 pounds and without any readjustment broke a horse hair at a load of one pound. "In seven weighings of a load of 100 pounds with the Watertown machine the greatest difference in the observed weights was $\frac{1}{1,750,000}$ of the load. In nine weighings of 200 pounds the difference was only $\frac{1}{2,350,000}$ of the load".Unwin.

Sensitiveness decreases with use since the friction on the knife edges increases as they become dulled by rolling on their supports and by impact in recoil.

The friction does not increase much with load and hence proportional sensitiveness increases. This is not true of most hydraulic machines, although it is of the Phoenix, due perhaps to the special design of the packing of ^{piston} which has been described.

2. Accuracy is as essential as sensitiveness and, of course, a very sensitive machine may be inaccurate.

Errors may be due either to a lack of knowledge as to the true leverage ratio, to incorrect weights, to inertia forces, or to deflection of the levers.

The leverage ratio may be that given by the manufacturer and not verified by user. This ratio will change

slightly to one side or the other. Errors of this nature produce least effect when distance between knife edges are large as in Buckton-Wicksteed machine and most effect when knife edges are close together as in Werder machine.

Weights may easily be standardized and this source of error need not be discussed.

It is a known fact that the inertia forces influence readings very materially and hence the adoption of standard rates of applying the load in order that accurate comparisons may be made. Mr. Gus C. Henning says of this, "It is well known that in the Carnegie Works you test so fast that you simply take the man's word for it that it carried so much. But if you know your business you do not let them run a machine so fast." With an Emery machine, however, this is different, and as long as indicator needle is floating, the correct stress is indicated.

Errors due to deflection are hard to combat and can be taken care of only by a thorough and complete calibration throughout the whole range of the machine. Stiffness of the levers should be sought as well as strength and it is very advisable to make an investigation of the flexure throughout large variation in the stress.

Measurement of the knife edge distance is rarely satisfactory, and it is much better that the leverage be obtained by weighing and that this test be applied occasionally afterwards.

Least in accuracy of the machines in common use are the hydraulic machines, inaccuracies being due to the ever changing friction of the moving parts and errors of the measuring gauges. The accuracy of this type is quite sufficient however

for ordinary commercial testing of full sized members.

Knife edge machines rank next in accuracy while the manometer measuring machines of the Emery type are the most accurate, ⁽²⁾ the Watertown machine being the most accurate testing machine in the world. (?) H.F.M.

3. By adaptability is meant the quality of easy changing from one kind of test to another and from one size of specimen to another, also the variety of work it is possible to do.

It is conceded that in adaptability the horizontal machine surpasses because in this type in moving about the heavy and cumbrous parts they need not be lifted or lowered but are merely shifted horizontally into required position. *Not for cross bending however*

4. For convenience in manipulation, the grips should be easy of access and the operating levers so arranged that all are within reach and placed so that specimen and scale beam can be watched throughout test.

5. Simplicity of design is desirable for several reasons. When there are but a few parts the operator is much less apt to make mistakes and can give more attention to the behavior of the test piece. Complications, if any, are almost always in the weighing apparatus either in the multiplication of levers and knife edges or in use of variable weights. Besides adding to the complexity, these features increase initial cost and cost of repairs. The Buckton-Wicksteed is recommended for its simplicity on account of its single lever, considerable fulcrum distance, and constant poise weight.

As embodying the qualities enumerated above and

considering their uses, the following may be said:-

For commercial rapid testing for which no great refinement is required the horizontal hydraulic machines such as that at Phoenixville are the best adapted. *too general*

For a great variety of work such as will occur in the college laboratory, more refined than commercial tests, the Olsen, Riehle, Buckton-Wicksteed, Werder and similar machines are recommended.

For the highest degree of precision and accuracy the Emery machine is best.

V.

FALKENAU-SINCLAIR AND OLSEN PLANS.

Specifications.

It was desired in connection with the Engineering Experiment Station at the University of Illinois, to secure a testing machine which would be capable of taking columns, long test pieces, beams, large irregular shapes, reinforced concrete, stone and brick construction, built up metal trusses, and a great variety of test pieces of considerable size.

Designs were submitted by three firms, Tinius Olsen and Company, Falkenau-Sinclair Machine Company, and Riehle Brothers Testing Machine Company.

The Olsen plan embodied the characteristic features of the Olsen, the principal change being the addition of a fifth column to act as a guide for the traveling cross head. Three screws were used which provided for a movement of pulling head, without readjustment, of something less than eight feet. Three adjustable bars supplemented the screws and provided an adjustment to take care of differences in length of specimen.

The Falkenau-Sinclair Machine Company submitted four designs. All had a clear distance of thirty-six inches between pulling screws or pulling rods and were capable of taking specimens twenty-five feet in length with a capacity of 600,000 lbs. in each case. The floor space to be occupied was about 18 feet by 9 feet. The machines were designed for making transverse

tests with eight feet as distance between supports without extension to table.

The weighing mechanism consisted of cast steel levers with seats of hardened tool steel let into machined bearings. The poise was to consist of two sections one of which could be moved out at a time. Five speeds were provided of 0.05, 0.25, 1, 3, and 10 inches per minute respectively.

Machine "D", the fourth of the four designs submitted, was considered the best type for the purposes desired. This consisted of two heads connected by three pulling rods which were made in sections part of which could be removed for long specimens in tension and short specimens in compression. The lower head was provided with a nut through which passed the single screw which furnished the load. The weighing head, in addition to the two other pulling heads, was capable of but one position, at top of weighing columns, thus necessitating the use of the upper part of the machine for all tension tests.

The machine was designed for a capacity of but 300,000 pounds on tensile specimens of very inextensible material. The specifications provided for an eccentricity of six inches when this was divided evenly between top and bottom. A sensitiveness of $\frac{5}{10,000}$ at full load, and of $\frac{2}{10,000}$ at a load of 10,000 pounds when loaded normally. With eccentric load a sensitiveness of $\frac{10}{10,000}$ was to be attained.

The design adopted was that of Riehle Brothers Testing Machine Company as modified by Professor Talbot.

The specifications are found on the succeeding pages.

SPECIFICATIONS
for
600,000 lb. RIEHLE VERTICAL SCREW POWER TESTING MACHINE for
UNIVERSITY OF ILLINOIS

April 14, 1904.

DIMENSIONS.

Extreme Height,	36 ft. 0 in.
Extreme Length including Motor,	17 ft. 0 in.
Extreme Width,	10 ft. 8 in.
Height above floor,	30 ft. 0 in.
Weight,	100,000 lbs.

ADAPTATION.

Compression Specimens, 25 ft. 0 in. long and less.
 Tensile Specimens, 22 ft. 0 in. long, with 20% elongation in 20 ft. and more for shorter lengths.
 Transverse Specimens, 10 ft. 0 in. long by 3 ft. 0 in. wide and less.
 Tensile Tools, viz. Grips and Liners, to take specimens 6 in. round or square and less, to $\frac{3}{4}$ in. round or square; 12 in. by 4 in. flats and less.
 Compression Tools 29 in. square, and hardened steel plates 6 in. square.
 Transverse Tools, 3 ft. 0 in. wide by 18 in. high.
 All Tools will be provided with handles to facilitate placing them in the machine. The Compression Tools will consist of two flat blocks of cast iron, one to be held in pulling head and one to rest on table of the Machine; these tools are used for specimens of large area. 6 in. square hardened steel plates are provided to be used for specimens of smaller area. The Transverse Tools are of the usual form of V blocks, one to be held in the pulling head and two to rest on the table of the Machine. T slots are provided in the table for holding these tools in place.
 The Speeds of Machine at 300 r.p.m. of the driving shaft are;
 Speed for Setting Head, 8 in. per minute.
 Quick Speed for Testing, 2 in. " "
 Medium Speed for Testing, 1 in. " "
 Medium Speed for Testing, .4 in. " "
 Slow Speed for Testing, .1 in. " "
 Slow Speed for Crushing Test, .05 in. " "
 15 Horse Power will be required to operate this Machine using as a maximum speed 1 in. per minute to full capacity of Machine, and 2 in. per minute to one-half the capacity of Machine.

ACCURACY.

The accuracy of this machine will be within one-third of 1% of the reading on the beam. This will represent a possible maximum error of 2000 lbs. when the machine is at its full capacity, and of 200 lbs. when the Machine is under load of 60,000 lbs.

SENSITIVENESS.

A Needle Beam will be provided for obtaining greater sensitiveness. This Beam will be moved not less than one-half inch at the extreme end by a load equal to one-sixth of 1% of the reading on the Beam. This will represent a variation of 1000 lbs. when the Machine is at its full capacity, and of 100 lbs. when the Machine is under load of 60,000 lbs.

CALIBRATION.

The Machine will be calibrated at our Works and after it is set in place at the University. Riehle Standard Calibrating Levers will be used to calibrate the Machine to one-tenth the capacity, viz. 60,000 lbs. These Levers will have a count of ten to one, and 6000 lbs. placed on the bales will represent a load of 60,000 lbs. on the Beam of the Machine. The Machine will also be calibrated by as much dead weight placed on the weighing table as is possible to be attained.

A Calibrating Bar and Extensometer of accepted design, both to be furnished by, and to be the property of, the University of Illinois, will be used to calibrate the Machine to full capacity.

The Machine is to be calibrated by our Engineer in the presence of a representative of the University of Illinois and is to be approved by said representative.

ERECTION.

The erection of the Machine is to be superintended by our Engineer, we to allow him two weeks for this purpose; the University to furnish such help as may be required in the judgement of our Engineer.

The foundation is to be built by the University at their expense, from drawings furnished by us and to be in place ready for erection of Machine before such time as our Engineer shall arrive on the ground.

RECOIL.

Recoil Bolts will be provided to check the recoil of the weighing table and other parts caused by the breaking of tensile specimens. The ability of Machine to withstand recoil is to be tested breaking a cast iron specimen of such diameter as will require nearly the full capacity of the Machine. 6 in. will be the maximum size of the specimen which the University is to furnish for this purpose.

STEEL CASTINGS.

The parts of the Machine which are to be made of steel castings are as follows: Weighing Table, Main Levers, Weighing and Pulling Heads, Main Gears, Bevel Gear, Speed Clutches and such Speed Gears as are necessary.

PULLING SCREWS.

Two Screws will be used for applying the strain. These screws will be made of special screw steel with a tensile strength of 80,000 lbs. per square inch and with an elastic limit of 40,000 lbs. per square inch. They will be 5 1/2 in. outside diameter and 4 3/4 in. diameter at the root of the thread.

There will be no binding action of the screws due to the eccentricity caused by the loading of the specimen 5 in. out of center to the full capacity of the Machine.

DRIVING MECHANISM.

All gears are to be cut gears and spur gearing is used throughout with the exception of one train of bevel gears. Six speeds are obtained and are as given in the Adaptation. Two levers are used for obtaining these speeds, one of the levers operating an interlocking mechanism which makes it impossible to throw in more than one speed at one time. This prevents the breaking of the speed gears. A third lever is used for operating the friction clutches which start, stop and reverse the pulling head of the Machine.

GUIDE COLUMNS.

These Columns are used to guide the pulling head and to take the side thrust caused by the eccentric loading of a compression specimen, and are of such strength as to take a side thrust of 10,000 lbs. 10 in. from the extreme top and of 20,000 lbs. 13 ft. 4 in. from said top, and either parallel or perpendicular to the direction of the weighing beam of machine. These Columns are so fastened to the body of the Machine and to the foundation as to resist the bending moments produced by the side thrust.

The Columns are tied together by steel tie rods both in planes parallel and perpendicular to the weighing beam, said tie rods to be spaced as shown on drawing T-60 A-1773. These tie rods hold the columns together against strains caused by the side thrust and spreading action. The design is such as to resist a spreading force of 125,000 lbs. with the pulling head at any position.

WEIGHING COLUMNS.

These Columns carry the weighing head and are provided with three slots for receiving the two keys or bars which hold this head in any one of the three positions. The weighing head is moved from one position to the other by means of

the pulling head, the keys being first withdrawn after the pulling head has been run so that it is contact with the weighing head, both heads being moved to the desired position and the keys placed in the slots so as to support the weighing head.

PULLING HEAD.

This head slides in the guide columns and is provided with guides 24 in. in length. The total area of the bearing surface of the head against the guide columns is 192 square inches.

OPENING IN HEADS.

The opening in the pulling and weighing heads is shown by drawing T-60 A-1772 and is such that a bar 6 in. diameter or 12 in. by 4 in. flat will pass through.

MAIN WEIGHING LEVERS.

These levers are made of steel castings and are of the design as shown by Blue Print T-60 A-1767-13. With this design a maximum rigidity of the knife edges is obtained and the strain is transmitted from one knife edge to the other in a direct line, that is, a line can be drawn which will strike the center of each of the three knife edges.

The average pressure per linear inch on the knife edges of these levers is 9375 lbs. On the intermediate levers the pressure on the knife edges is less than this. The Lloyd's Register of British and Foreign Shipping requires "The length of the knife edges should not be less than at the rate of one inch for every five tons of pressure upon them." This requirement is conformed with in the Riehle Machine by using less pressure than is asked for by Lloyd's.

WEIGHING BEAM.

The Weighing Beam is the most improved type of the Riehle Dial Screw Beam. The Beam is graduated in 10,000 lb. marks and from the dial at the operating end of the beam the 1000 lbs. and 100 lbs. are read, the smallest reading on the dial being 100 lbs. Two poises are used. If so desired, the forward poise can be run out and will automatically release itself; the other poise can be thrown in and run out, or if desired both can be run out together. The pieces at the far end of the beam represent the full capacity of the Machine, and no end weights are required.

SUPPLEMENTARY SPECIFICATIONS
for
600,000 lb. RIEHLE VERTICAL SCREW POWER TESTING MACHINE for
UNIVERSITY OF ILLINOIS.

May 2, 1904.

STRUTS FOR GUIDE COLUMNS.

Cast Iron Struts will be furnished to tie the guide columns together at the lower end. A sketch which is attached to these Specifications shows the form in which they will be made. Cast Iron Struts will be furnished to stiffen the guide columns at the top, a sketch of which is shown by Fig. 7.

TRANSVERSE TOOLS.

Transverse Tools 12 in. high, the base to be made on a 12 in. radius, as shown by Fig. 6 on accompanying sketches, will be furnished in place of the regular V block tools. Two of these tools will rest on the table. The upper transverse tool is of the V block type, and is bolted to head.

STRESSES.

In designing the Machine the intensity of the fibre stresses does not exceed the following values:

Cast Iron,	Transverse 5000 lbs. per sq. in.
	Compression 12000 lbs." " "
Machinery steel including bolts,	Tension 20000 lbs. per sq. in.
Steel Castings,	Transverse 12000 lbs. per sq. in.

In the majority of cases the stresses are less than the above figures.

WORKMANSHIP.

The workmanship on all parts of the Machine is to be of the best quality and the satisfactory operation of the Machine is guaranteed.

RECOIL.

A Recoil device will be provided to check the recoil in a satisfactory manner so that no bad effects will result to the Machine from the breaking of a cast iron specimen tested for tension with the weighing head in the extreme top position. The specimen to be of such size as to require the full capacity of the Machine as before mentioned in the specifications. The taking care of the recoil will be accomplished by means of hydraulic cylinders or other desirable means.

A recoil of the pulling screws will be transmitted through the massive base of the Machine to the foundation.

ERECTION.

The erection of the Machine is to be superintended by our Engineer and we will allow him such time at the University as may be necessary, without expense to you. The University to furnish our Engineer with such help as may be required in his judgement.

VI.

DESCRIPTION.

The general plan and outline of the machine can be seen on accompanying figure. The general dimensions are given in the specifications which immediately precede this description.

The machine rests on a concrete foundation and is placed in a central position in the laboratory. Upon the foundation is the bed plate and upon it in turn rest the legs, cover plate, main levers, and weighing table respectively. The guide columns are bolted to the bed plate and foundation and stand at the four corners of the machine. Upon the weighing table are supported the weighing columns which carry the upper, or weighing head. The two screws pass down through the table and cover plate and carry the pulling head. The screws are in a north and south plane. The main bracket extends to the south and carries the gearing and the weighing lever system, excepting the main levers as mentioned before. The motor is in the south-east corner of the pit which carries the lower part of the machine, the top of the weighing table being about two inches above the floor level.

The foundation is of concrete in the proportions , is four feet in thickness, and underlies the entire pit.

The members will be taken up separately. Weights and material are to be found under the investigation of the design.

The bed plate is 1 1/2 inches thick. The dimensions

are shown in figure under computations.

The legs are about 24 inches deep and semicircular in shape. They support the cover plate and contain between them the gears driving the screws.

The cover plate is approximately five feet wide, eight feet four inches long, and thirteen inches deep. Lugs on upper face carry steels upon which levers are supported. Roller bearings beneath cover plate transfers load from screws to foundation. *cover plate*

The main levers, of which there are four, are one of the features of the design. Instead of the ordinary single webbed lever, double webbed levers are used which makes the knife edges act as restrained beams instead of as cantilevers, thus greatly reducing the deflection of knife edges and causing the load to be more evenly distributed over same. Another feature is the fact that the middle points of the three knife edges are all in a straight line with no point in the levers at any great distance from this line, thus reducing torsional strains.

The weighing table has for its extreme dimensions the following:- Length, 10 ft. 6 in.; breadth, 6 ft. 5 in.; depth 24 in. The ordinary depth is 15 inches. ^{Sixteen} two inch tapped holes are provided in table for the insertion of bolts to hold specimens or tools.

The weighing columns are in three sections tied together at the top. It was found during the tests with eccentric loading that there was not sufficient clearance between the flanges of the columns and the pulling head. To take care of the maximum deflection it will be necessary to remove about 1 1/2

inches from flanges. This, however, will not make stresses too excessive, latter being increased to about 5100 pounds per square inch. The weighing head can be keyed in any of three positions by means of four keys, two at each end. Maximum depth of head is twenty inches.

There are two screws 5 1/2 inches in diameter to outside of thread and 4 3/4 inches in diameter at base of thread. Pitch is one inch. Guides are provided at the top head of weighing columns for screws but these are of doubtful utility.* The bearing of screws is about four feet. ✓

The four guide columns are also in three sections and are designed to carry side thrust due to eccentric loading and to carry the twisting action of pulling head due to friction between nut and face of screw heads. ^{threads} The guide columns are tied to each other in both directions.

The pulling head has a maximum thickness of sixteen inches. Bearing surface is .24 inches out to out. Openings in the heads are large enough to take flat specimens four inches by twelve inches or round specimens six inches in diameter.

The weighing mechanism consists of five levers including the main levers and needle beam. Their counts are 10, 8, 6, 12, and 10 respectively making a leverage of 57,600. Hence weight of large poise should be 104.17 lbs. theoretically. In addition to the large poise there is a small poise which can be used independently and with which the actual load is one-tenth of that indicated by scale beam and by means of which sensitive-ness is increased considerably. The beam is graduated to 10,000 pounds reading to 100 pounds by means of the dial.

The accidental loosening of one of these guides showed that guides were absolutely necessary to keep screws from vibrating dangerously.

A diagram of the gearing is shown on next page.

The main gears A A are keyed to the screws and driven by the main pinion B through the bevel gear C and bevel pinion D.

1. With clutch O in the driving pinion 10 and clutch N in 5 the speed of eight inches per minute is obtained. Same with clutch N in 3 instead of 5 reduces speed to two inches per minute. Same with clutch N free and clutch M in 1 gives speed of one inch per minute.

2. With clutch O in back gear 8, latter is driven through 9 and 7 and with clutch N in 5 speed of 0.4 inches per minute is obtained. With clutch N in 3 a speed of 0.1 inches per minute is given while clutch N free and clutch M in 1 gives the slowest speed .05 inches per minute. The speed of driving shaft from motor is 300 r.p.m.

The number of teeth in the gears are as follows:--

1-120; 2-15; 3-108; 4-27; 5-68; 6-67; 7-24; 8-111; 9-111; 10-24;
11-72; 12-18; 13-64; 14-18; 15-24; A-80; B-14; C-90.

All gears are cut gears and of cast steel except 14 ^{and 15 are of C.I.} which is rawhide. There are but two bevel gears, C and D.

The tools are described sufficiently in the specifications.

The hydraulic cylinders used to dissipate the energy of recoil are also a new feature. There are four cylinders of eight inches internal diameter which are carried at the four corners of the table. Plungers fixed to lugs on the guide columns are forced down into these cylinders by the use of the table in recoil. The cylinders are kept filled by a tank at top of columns and when plungers are forced down into them the liquid, oil, is

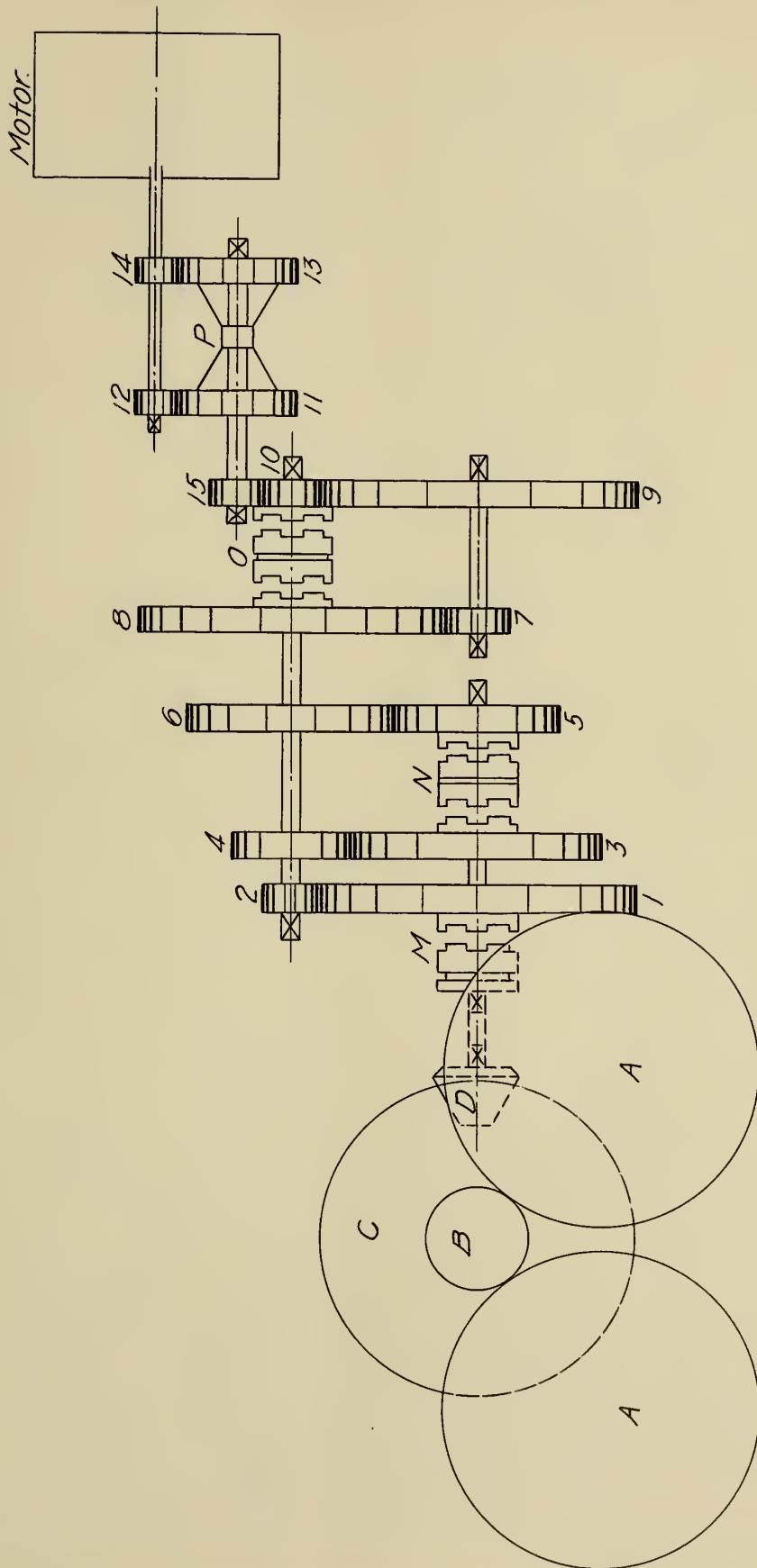


Diagram of Gearing.

forced to pass through a needle valve, slowly using up the energy of recoil.

The motor used is a Westinghouse 15 H.P. induction motor, direct connected.

VII.

INVESTIGATION OF DESIGN.

The main features of the design will now be taken up and discussed. The outline below gives the order which will be followed in the computation of stresses.

Bed Plate--bearing area.

Legs--cross section.

Cover Plate--distribution of load upon webs.

Levers--stresses- form. Deflections of levers and of knife edges.

Weighing Table--influence of deflection.

Weighing Columns--stresses of fibers and at joints.

Screws,-stress, ordinary and under unequal stretch--shear in threads.

Pulling Head--side action--stresses--shear in collar.

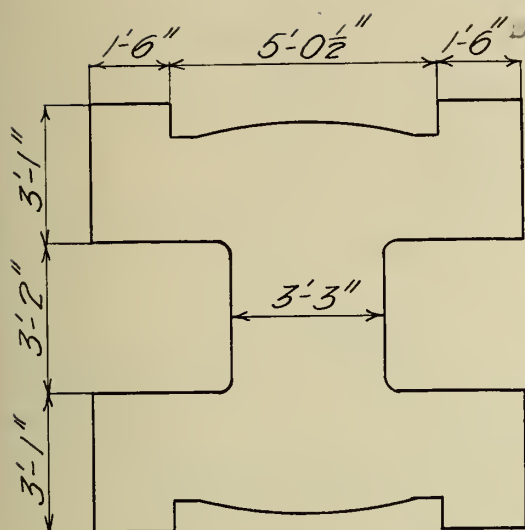
Weighing Head--stresses.

Guide Columns--stresses due to eccentric loading--stresses in bolts--deflections.

Recoil.

COMPUTATION OF STRESSES.

Investigation of Design.



Bed Plate

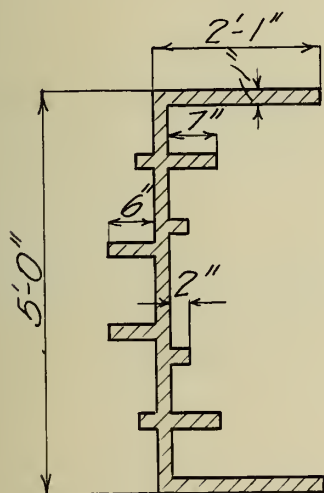
Area = 55 square feet

Total weight = 65 tons

Load per square foot = $\frac{65}{55} = 1.2$ tonsArea under guide columns and table
has area of about 35 square feet.Load per square foot = $\frac{65}{35} = 1.86$ tons

Weight of bed plate = 3,000 pounds

Material cast iron



Legs

Area = 142 square inches (one leg)

Load supported by both legs = 50 tons

Unit load = $\frac{50(2000)}{2(142)} = 350$ pounds

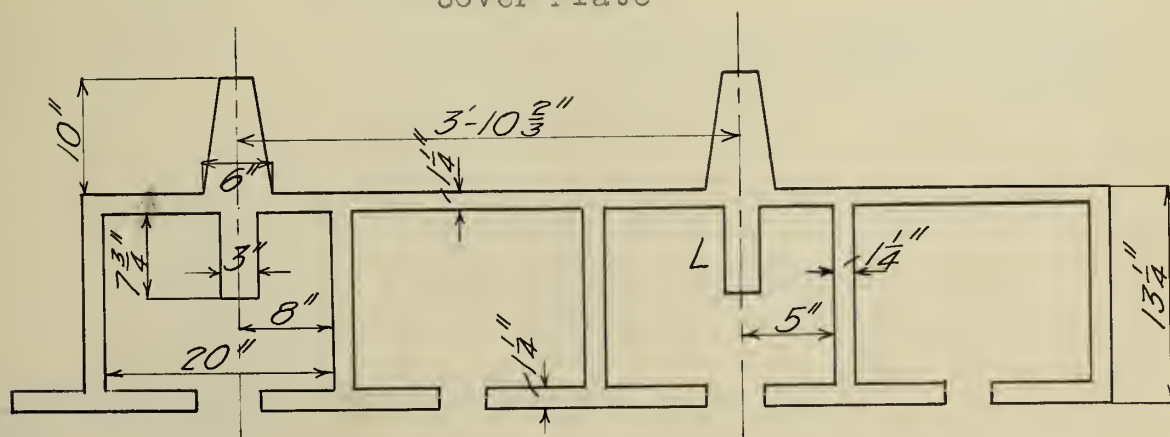
per square inch which is very safe

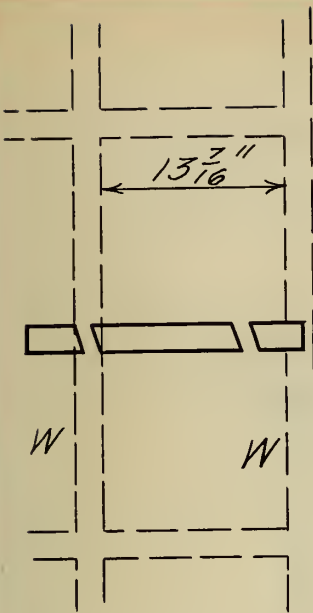
Weight of front leg = 2,000 pounds

" " back " = 2,000 "

Material cast iron

Cover Plate





Investigation will be made of the distribution of the load from lugs L to webs W of cover plate. Lug extends between webs W , and part of load of $\frac{600,000}{4}$ carried by knife edges over lug = 135,000. Regarding lug as a beam fixed at both ends moment = $\frac{1}{12} Wl$,
 $= \frac{1}{12} \times 135,000 \times 13 \frac{7}{16} = 152,000$ inch pounds.

$$\text{Modulus of lug} = \frac{1}{6} bd^2 = \frac{1}{6} \times 3(7 \frac{3}{4})^2 = 30.$$

$$\text{Fiber stress} = \frac{152,000}{30} = 5060.$$

Allowable = 5,000 pounds per square inch.

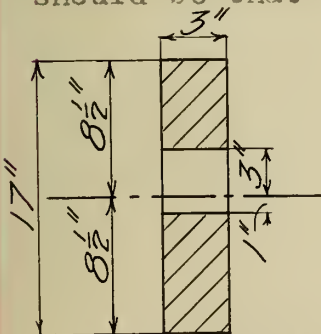
It is not necessary to investigate the stresses in web flanges which are somewhat indeterminate.

Material cast Iron.

Weight 8500 pounds.

Levers

Levers are cantilevers loaded at end. For uniform strength outline should be that of a parabola when breadth is uniform.



(a) Back lever. Take section under middle knife.

$$\text{C.G.} = \frac{17 \times 3 \times 8 \frac{1}{2} - 4 \times 3 \times 9 \frac{1}{2}}{17 \times 3 - 4 \times 3} = 8.2$$

from bottom.

$$I = \frac{(3)17^3}{12} + (3)17(0.3)^2 - \left[\frac{(3)4^3}{12} + (3)(4)(1.3)^2 \right] = 1230 - 36 = 1194.$$

$$\text{Modulus} = \frac{1194}{8.2} = 145.6.$$

$$\text{Moment} = \frac{600,000}{4} \times \frac{9}{16} \times 9.667 = 1,305,000.$$

$$\text{Stress} = \frac{1,305,000}{145.6} = 9,000 \text{ pounds.}$$

Allowable stress = 12,000 pounds.

For uniform strength depths of lever should be as shown in table below.

Distance from Middle Knife Edge	Theoretical Depth	Actual Depth	
0 in.	17.07 in.	17.07 in.	*
10 "	16.8 "	15.1 "	
20 "	16.1 "	14.1 "	
30 "	15.0 "	13.1 "	
40 "	13.5 "	11.1 "	
50 "	11.4 "	10.5 "	
60 "	8.9 "	9.0 "	
70 "	6.0 "	7.1 "	
80 "	2.7 "	5.0 "	

* Equivalent without hole, stress on lower fibre considered.

As is seen here the actual depth does not give uniform strength. However, the weight of lever would tend to make curve tend to change from parabola to a straight line but not much.

$$\text{Stress at twenty inches} = \frac{(15,000)(67)}{\frac{(3)(14.1)^2}{6}} = 10,100.$$

From computations following it is seen that maximum bending stress comes where torsional stress is maximum but combined stress is safely carried.

To secure an even distribution of stress as possible on knife edges the centers of front steel, middle steel and rear steel all lie on same straight line in all cases.

The stress due to torsion is maximum at point where back levers come nearest to pulling screws. Moment arm here equals about three inches. Hence twisting moment =

$$(15,000) 3 = 45,000.$$

Section of lever here is 11 1/2 x 3.

Saint Venant's formula (Kent p.282) for rectangular shafts is,

Moment = $\frac{(\text{Stress})(\text{Area})^2}{3b + 1.8d}$ where b is longer side and d is shorter side.

$$\text{Hence } 45,000 = \frac{(\text{Stress})(11.5 \times 3)^2}{(3)(11.5) + (1.8)(3)}$$

Hence torsional stress = 1,510.

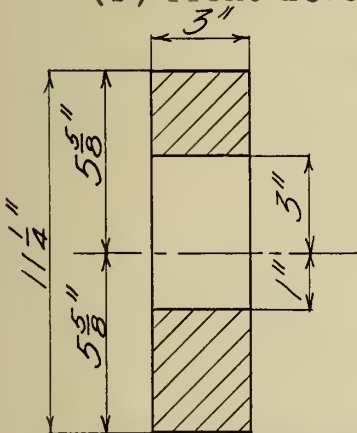
$$\text{Stress due to bending here} = \frac{m}{\frac{I}{c}} = \frac{(15,000)(48)}{\frac{(3)(11 \frac{1}{2})^2}{6}} = 10,900.$$

For combined tension and torsion

$$\begin{aligned} f &= 1/2(S + \sqrt{S^2 + 4S_s^2}) \\ &= 1/2(10,900 + \sqrt{10,900^2 + 4(1510)^2}) = 1/2(10,900 + 11,000) = \\ &11,000. \end{aligned}$$

Allowable = 12,000 pounds per square inch.

(b) Front Lever.



$$\begin{aligned} \text{C.G.} &= \frac{11 \frac{1}{4} \times 3 \times 5 \frac{5}{8} - 4 \times 3 \times 6 \frac{5}{8}}{11 \frac{1}{4} \times 3 - 4 \times 3} = \\ &5.05 \text{ inches from bottom.} \end{aligned}$$

$$\begin{aligned} I &= \frac{3(11 \frac{1}{4})^3}{12} + 3(11 \frac{1}{4})(0.6)^2 - \\ &(\frac{(3)(4)^3}{12} + 3 \times 4 \times (1.6)^2) = 368 - 46 = 322. \end{aligned}$$

$$\text{Modulus} = \frac{322}{5.05} = 64.$$

$$\text{Moment} = (\frac{600,000}{4} \frac{9}{10} \times 5) = 675,000.$$

$$\text{Stress} = \frac{675,000}{64} = 10,600 \text{ pounds per square inch.}$$

Allowable = 12,000 pounds per square inch.

For uniform strength the depths of lever should be as shown in the table below,

Distance from Middle Knife Edge in.	Theoretical Depth in.	Actual Depth in.
0	11.3	11.3 *
5	11.2	10.0
9	10.8	9.5
13	10.3	8.9
17	9.6	8.4
21	8.8	7.8
25	7.8	7.1
29	6.6	6.3
33	5.2	5.5
37	3.6	4.8
41	1.9	not given

* Equivalent without hole, stress on lower fibre considered.

The same criticism may be made here as was made upon the proportioning of back lever.

The stress due to torsion is practically nothing.

$$\text{Stress at thirteen inch point} = \frac{m}{\frac{I}{c}} = \frac{(15,000)(32)}{\frac{3(8.9)^2}{6}} = 12,100.$$

Allowable = 12,000.

$$\text{Stress at seventeen inch point} = \frac{m}{\frac{I}{c}} = \frac{(15,000)(28)}{\frac{3(8.4)^2}{6}} = 11,900 \text{ lbs.}$$

2. Deflections.

(a) Of lever.

$$d = \frac{1}{3} \frac{Pl^3}{EI} = \frac{P}{3E} \frac{l^3}{I} = \frac{15,000}{90,000,000} \times \frac{l^3}{I} = \frac{1}{6,000} \frac{l^3}{I}$$

$$\text{Front lever, } d = \frac{1}{6,000} \frac{45^3}{322} = 0.047.$$

$$\text{Back lever, } d = \frac{1}{6,000} \frac{87^3}{1194} = 0.091.$$

Shortening of levers due to deflection.

$$\text{Excess of arc over chord} = \frac{8}{3} \frac{m^2}{c} \quad \text{in which } m = \text{deflection,}$$

$c = 2l$.

$$\text{Front lever excess} = \frac{8}{3} \frac{(0.047)^2}{(2)(45)} = 0.000065.$$

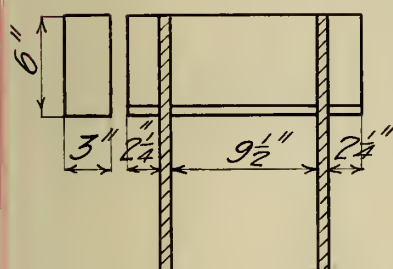
$$\text{Back lever excess} = \frac{8}{3} \frac{(0.091)^2}{(2)(87)} = 0.000127.$$

$$\text{Difference} = 0.000127 - 0.000065 = 0.000062.$$

This is entirely negligible.

(b) Of Knife Edges.

The steel is backed by its lug and central portion acts



as a beam fixed at both ends while outside portions act as cantilever beams.

$$\text{Deflection in center} = \frac{Wl^3}{384EI}$$

$$\text{Deflection at end} = \frac{Wl^3}{8EI}$$

Rear knife edge of front lever.

$$W(\text{central portion}) = \frac{9.5}{14} \times 135,000 = 91,600.$$

$$I = \frac{(3)(6)^3}{12} = 54.$$

$$\text{Hence } d = \frac{(91,600)(9.5)^3}{(384)(30)(10)^6(54)} = 0.000126.$$

$$W(\text{end portion}) = \frac{2.25}{14} 135,000 = 21,700.$$

$$\text{Hence } d = \frac{(21,700)(2.25)^3}{(8) 30,000,000(54)} = 0.000019.$$

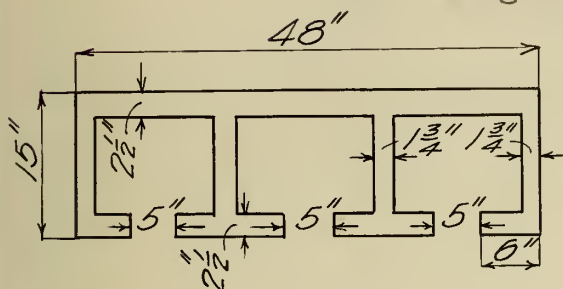
These are maximum deflections and are very slight, due to the increased rigidity given knife edge by separating web of lever.

It seems that load may be considered as evenly distributed over knife edge or pressure per linear inch = $\frac{135,000}{14} = 9,600$ pounds for rear steels of all levers and $\frac{150,000}{15 \frac{1}{2}} = 9,700$ for middle steels of front levers and $\frac{150,000}{16} = 9,400$ for middle steels of rear levers. Specifications give Lloyd's allowable pressure per lineal inch as five tons.

Material cast steel.

Weight, two 1750 pounds each, two 300 pounds each.

Weighing Table.



Section \perp to knife edges.

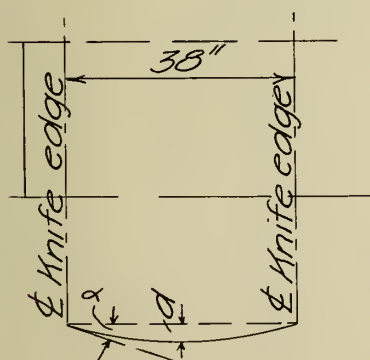
Area = $272 \frac{1}{2}$ square inches.

C.G. from bottom =

$$\frac{(48)(15)\frac{15}{2} - 10(41)7 \frac{1}{2} - \frac{(15)(2\frac{1}{2})^2}{2}}{272 \frac{1}{2}} =$$

8.36 inches.

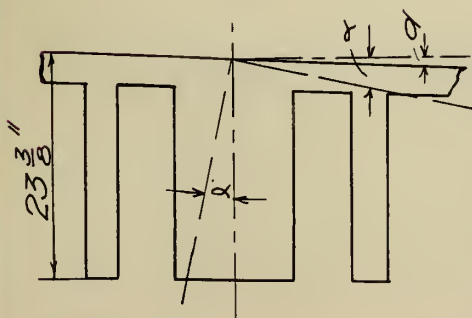
$$I = \frac{(48)15^3}{12} + (48)(15)(0.86)^2 - \left\{ \frac{(10)^3(41)}{12} + (41)(10)(0.86)^2 \right\} - \left\{ \frac{((15)(2 \frac{1}{2}))^3}{12} + (15)(2 \frac{1}{2})(7.11)^2 \right\} = 14,033 - 3,720 - 1,916 = 8397.$$



Regarding table as a simple beam supported at centers of knife edges and loaded in middle, to find additional load thrown on knife edges by deflection of table.

$$d = \frac{1}{48} \frac{Wl^3}{EI} = \frac{1}{48} \frac{(600,000)(38)^3}{(30,000,000)(8397)} = 0.0027.$$

$$\tan \alpha = \frac{2d}{\frac{l}{2}} = \frac{4}{38} 0.0027 = 0.00029.$$



Point of application of center of load is moved from center of knife edge by an amount equal to,

$$23 \frac{3}{8} \tan \alpha = (23 \frac{3}{8})(0.00029) = .00679 \text{ inches.}$$

$$\text{Let } n = \frac{\text{dist. from center}}{\text{length of steel}} = \frac{0.00679}{15.5(\text{front})} = 0.00044.$$

n is less than $\frac{1}{6}$ and Navier's principle will apply or

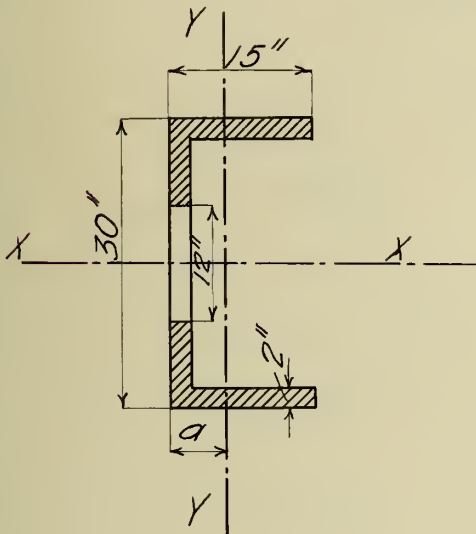
$$p_{\text{max.}} = p_{\text{mean}}(6n+1) = \frac{150,000}{15.5} (1.00264) = 97,000.$$

Hence table is sufficiently stiff.

Material cast steel.

Weight 12,000 pounds.

Weighing Column.



Area = 88 square inches.

$$I_x = \frac{(15)(30)^3}{12} - \frac{2(12)^3}{12} - \frac{(13)(26)^3}{12}$$

$$= 14,420.$$

$$a = \frac{2(30 \times 7 \frac{1}{2} + 14 \times 1)}{88} = 5.43$$

inches.

$$I_y = \frac{(30)(15)^3}{12} - \frac{(12)(15)^3}{12} -$$

$$2\left(\frac{(7)(13)^3}{12} + 91(1)^2\right) - 88(2.07)^2 =$$

$$1940.$$

Ritters rational formula.

$$\text{Stress}(x_x) = \frac{P}{A} \left(1 + \frac{S_e l^2}{m \pi^2 E r^2} \right) = \frac{300,000}{88} \left(1 + \frac{(20,000)(27 \frac{1}{4})^2 (12)^2}{\pi^2 15000000 \frac{14420}{88}} \right)$$

= 3700. (both round)

$$\text{Stress}(y_y) = \frac{P}{A} \left(1 + \frac{S_e l^2}{m \pi^2 E r^2} \right) = \frac{300,000}{88} \left(1 + \frac{(20,000)(27 \frac{1}{4})^2 (12)^2}{2 \frac{1}{4} \cdot \pi^2 15000000 \frac{1940}{88}} \right) =$$

4400. (one fixed, one round)

Stress xx (2 inches eccentricity, 600,000 pounds) =

$$\text{stress xx } \left(1 + \frac{pc_1}{r^2}\right) = 3700 \left(1 + \frac{(2)(15)}{\frac{14420}{88}}\right) = 4370.$$

Stress in bolts in flanges (bending parallel to beam).

$$\text{Bending moment} = \frac{SI}{c} = (4400) \left(\frac{1940}{9.57}\right) = 892,000.$$

Assume that this is carried by the four bolts having a moment arm of 16 1/2 inches.

$$\text{Stress per bolt} = \frac{892,000}{4(16.5)} = 13,500.$$

One and one-half inch bolts used. Diameter at base of thread = 1.25 inches. Area at base of thread = 1.23 square inches.

$$\text{Unit stress} = \frac{13,500}{1.23} = 11,000. \quad \text{Stress is actually smaller however since other bolts take part of moment.}$$

Consider joints with buckling perpendicular to beam. Maximum stress = 4370 (2 inches eccen.)

$$\text{Moment} = S \times \text{Modulus} = 4370 \frac{14420}{15} = 4,199,570.$$

Assume that the stress per bolt at unit distance = 10,000 pounds.

Then moment is distributed as follows:

2 at 5 1/4"	=	2(5 1/4) ² (10,000)	=	551,200
1 at 11"	=	(11) ² (10,000)	=	1,210,000
1 at 22 1/4"	=	(22 1/4) ² (10,000)	=	4,955,000
2 at 28"	=	2(28) ² (10,000)	=	15,680,000
3 at 33 1/4"	=	3(33 1/4) ² (10,000)	=	<u>33,195,000</u>
				55,591,200

Hence actual stress at unit distance

$$= \frac{4,199,570}{55,591,200} (10,000) = 750.$$

Hence stress per bolt distant $33 \frac{1}{4}$ inches

$$= (750)(33 \frac{1}{4}) = 24,900.$$

$$\text{Unit stress} = \frac{24,900}{1.77} = 14,100 \text{ pounds per square inch. Safe.}$$

Weight 3000 pounds each.

Six at 3000 pounds each = 18,000 pounds.

Screws.

(a) Stress in screws.

Under full load the unit stress in screws(5" eccent.)

$$= \frac{370,000(\text{see b})}{19.75} = 18,700 \text{ pounds per square inch.}$$

(b) Unequal stretch.

With maximum length of compressive specimen in machine the length of screw under tension is about thirty feet or three-hundred sixty inches. Consider full load with five inches eccentricity. Load on near screw =

$$= \frac{21+5}{42} (600,000) = 370,000 \text{ pounds.}$$

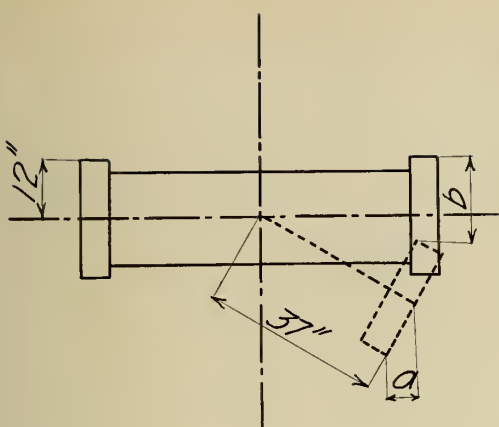
$$\text{Load on far screw} = 600,000 - 370,000 = 230,000 \text{ pounds.}$$

Average area of screw = $19 \frac{3}{4}$ square inches. Excess of fibre stress in more heavily loaded screw = $\frac{140,000}{19.75} = 7100$ pounds per square inch.

$$\text{Stretch of one screw in excess of other} = \frac{(360)(7100)}{30,000,000} = 0.085 \text{ inches.}$$

$$\text{Slope of pulling head} = \frac{.085}{42} = .002.$$

This slope decreases uniformly with length of specimen.



With 25 foot specimen.

b = vertical displacement of one end
of pulling head = $(37)(0.002) =$
0.074 inches.

a = horizontal displacement =
 $\frac{12}{37} b = \frac{12}{37}(0.074) = 0.024$ inches.

Hence if there is one-thirty-second

of an inch of play at each end of pulling head between it and guide columns, there will be no stress thrown in ties between guide columns due to eccentric loading. However if guides are tight the stretch of tie rods is $(2)(.024) = .048$.

Tie rods are six feet long = 72 inches.

Stretch per inch = $\frac{.048}{72} = .00067$.

Load to stretch bar $\frac{72}{\text{sq. in.}} (30,000,000)(.00067) = 20,000$ pounds.

" " " " one inch round = $(20,000)(.7854) = 15,700$.

At root of threads fiber stress = $\frac{15,700}{\pi(.84)^2} = 28,600$.

Guides are not perfectly tight and part of force used in stretching the rods and bending the columns is neglected.

Tie rods are six feet apart = 72 inches.

Moment < $15,700 \times \frac{72}{4} = 283,000$.

Modulus of guide columns = 267

Hence fiber stress < $\frac{283,000}{267} < 1050$. (which is stress due to unequal stretch of screws.)

Weight 2800 pounds each.

(c) Shear in threads at foot of screws.

Length of threaded portion = $3 \frac{1}{2}$ inches.

Outer diameter of threads = 5 inches.

Diameter at base of threads = 4.8

Efficiency assumed = $2/3$.

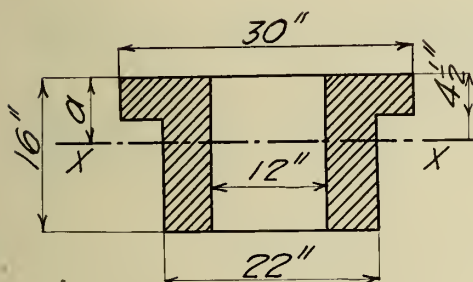
Shearing area = $(4.8)\pi(3\frac{1}{2}) \times \frac{2}{3} = 35.2$ square inches.

Unit stress = $\frac{370,000}{35.2} = 10,500$ pounds per square inch.

Pulling Head.

Side action of pulling head has been considered.

$$a = \frac{(8)(4\frac{1}{2})(2\frac{1}{4}) + (10)(16)8}{(8)(4\frac{1}{2}) + (10)(16)} = 6.95 \text{ inches.}$$



$$I_{xx} = \frac{(8)(4\frac{1}{2})^3}{12} + (8)(4\frac{1}{2})(4.7)^2 + \frac{(10)(16)^3}{12} + (10)(16)(1.05)^2 =$$

$$60.7 + 795.5 + 3413.3 + 176 = 4445.$$

$$\text{Modulus} = \frac{4445}{6.95} = 640 \text{ (tension fibre)}$$

$$\text{Bending moment} = (300,000)(21) = 6,300,000.$$

$$\text{Stress(tension)} = \frac{6,300,000}{640} = 9840 \text{ pounds per square inch.}$$

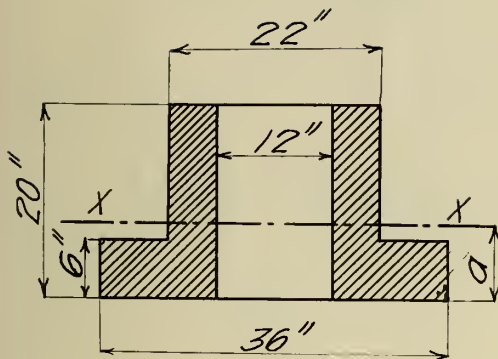
Shearing surface at collar of nut = $(9\frac{1}{4})\pi(3\frac{1}{2}) = 101.8$ square inches.

$$\text{Shearing stress(maximum)} = \frac{370,000}{101.8} = 3600 \text{ pounds per square inch.}$$

Weight 6000 pounds.

Position, action of pulling head neglected

Weighing Head.



$$a = \frac{(14)(6)(3) + (10)(20)(10)}{(14)(6) + (10)(20)} = 7.93.$$

$$I_{xx} = \frac{(14)(6)^3}{12} + (14)(6)(4.93)^2 + \frac{(10)(20)^3}{12} + (10)(20)(2.07)^2 = 252 + 2041.2 + 6666.7 + 856.0 = 9816.$$

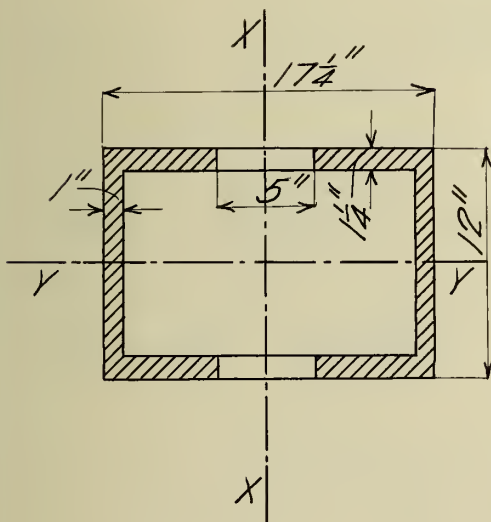
$$\text{Modulus} = \frac{9816}{7.93} = 1238 \text{ (tension fiber)}$$

$$\text{Bending moment} = (300,000)(30) = 9,000,000.$$

$$\text{Stress(tension)} = \frac{9,000,000}{1238} = 7270 \text{ pounds per square inch.}$$

Weight 4000 pounds.

Design stress is unity of 100,000 psi



Guide Columns.

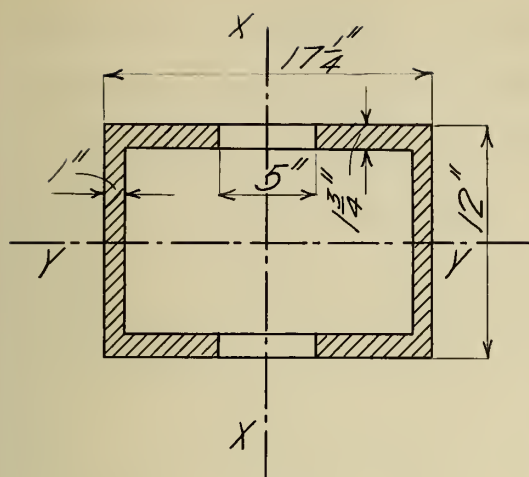
Top two sections are as shown in sketch. Area = 42.6 square inches.

$$I_{xx} = \frac{(12)(17 \frac{1}{4})^3}{12} - \frac{(9 \frac{1}{2})(15 \frac{1}{4})^3}{12} - \frac{(2 \frac{1}{2})(5)^3}{12} = 2300.$$

$$\text{Modulus} = \frac{2300}{8 \frac{5}{8}} = 267.$$

$$I_{yy} = \frac{(17 \frac{1}{4})(12)^3}{12} - \frac{5(12)^3}{12} - \frac{(10 \frac{1}{4})(9 \frac{1}{2})^3}{12} = 1030.$$

$$\text{Modulus} = \frac{1030}{6} = 172.$$



Bottom section is as shown in sketch.

Area = 59.8 square inches.

$$I_{xx} = \frac{(12)(17 \frac{1}{4})^3}{12} - \frac{(8 \frac{1}{2})(15 \frac{1}{4})^3}{12} - \frac{(3 \frac{1}{2})(5)^3}{12} = 2590.$$

$$\text{Modulus} = \frac{2590}{8 \frac{5}{8}} = 300.$$

$$I_{yy} = \frac{(17 \frac{1}{4})(12)^3}{12} - \frac{5(12)^3}{12} - \frac{(10 \frac{1}{4})(8 \frac{1}{2})^3}{12} = 1240.$$

$$\text{Modulus} = \frac{1240}{6} = 207.$$

With load having an eccentricity of five inches the side thrust is equal to 10,000 pounds at top of guide when twenty-five foot specimen is used or 20,000, 12 1/2 feet from top when specimen is 12 1/2 feet long.

$$\text{Maximum bending moment} = 21 \times 12 \times 20,000 = 5,040,000.$$

$$\text{Stress} = \frac{5,040,000}{4(300)} = 4200. (\text{about } xx)$$

For two inches eccentricity at right angles to beam

$$\text{Stress} = \frac{2}{5} \frac{5,040,000}{4(207)} = 2400.$$

To avoid twisting stress on bed plates guide columns are fastened to foundation by anchor bolts as well as to bed plate.

Bending moment from above is 5,040,000 or $\frac{5,040,000}{4} = 1,260,000$ inch pounds on each column. Bolts are thirty inches apart.

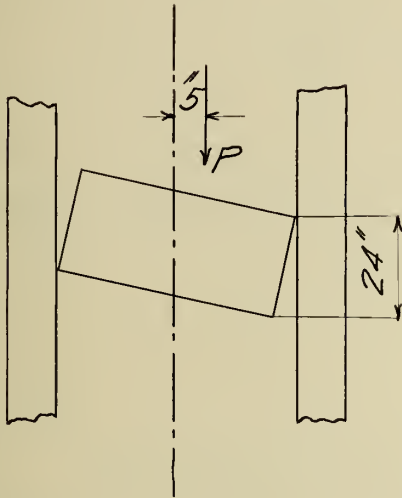
203 bolts on each side

$$\text{Stress in each} = \frac{1,260,000}{30} = 42,000 \text{ pounds.}$$

One and one-half inch bolts are used with an area of 1.30 square inches at root threads. Moment arm is only thirty inches approx-

imately. It would be somewhat smaller than this, being measured from the center of pressure of the side about which column tends to rotate. In addition columns are bolted to bed plate by four tap bolts with same moment arms.

Spreading action of pulling head.



With five inches eccentricity the bursting force exerted on tie rods =

$$\frac{5}{24} (600,000) = 125,000 \text{ pounds.}$$

Tie rods are six feet apart = 72 in.

Regarding column between tie rods as a beam loaded at center the bending moment on each column =

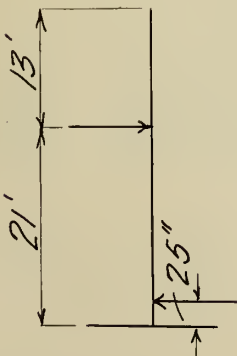
$$\frac{125,000}{2} \times \frac{72}{4} = 1,125,000.$$

Modulus of column (top section) = 267.

$$\text{Stress} = \frac{1,125,000}{267} = 4200 \text{ pounds per square inch.}$$

Side swaying of guide columns.

Consider bending parallel to beam with force of 20,000 pounds 12 1/2 feet from top of column



Shearing force on the bolts in cover plate which are twenty-five inches from base of columns =

$$\frac{21}{25} (20,000) = 201,600.$$

$$\text{Force on each column} = \frac{201,600}{4} =$$

50,400 pounds.

Area of three $1 \frac{5}{8}$ " bolts = 4.56 square inches

Unit shearing stress = $\frac{50,400}{4.56} = 11,000$ pounds per square inch.

Deflection of Guide Columns.

Load = 10,000 pounds. Length = 31 feet approximately.

Deflection = $\frac{1}{3} \frac{Wl^3}{EI} = \frac{1}{3} \frac{(10,000)(31)^3(12)^3}{(15,000,000)(1240)} = 2.29$ inches.

About other axis $d = 1.10$ inches.

Weight 9000 pounds each.

Recoil.

The energy stored up during the straining of a tensile specimen will be the maximum stored up and is stored up (a) in the compressed weighing columns, (b) in the bent weighing head, (c) in the bent levers.

(a) Compression of weighing column.

Let P = load on one column = 300,000 pounds.

A = area of " " = 88 square inches.

E = modulus of elasticity = 15,000,000.

l = length of column in inches = $27' 3" = 327$ inches.

c = compression of column

$$c = \frac{Pl}{AE} = \frac{(300,000)(327)}{(88)(15,000,000)} = .0743.$$

(b) Bending of Weighing Head.

Let W = load on head = 600,000 pounds.

l = span of head = 60 inches.

E = modulus of elasticity = 30,000,000.

I = moment of inertia = 9816.

δ = deflection.

$$\delta = \frac{W}{48} \cdot \frac{l^3}{EI} = \frac{600,000}{48} \cdot \frac{(60)^3}{(30,000,000)(9816)} = .0092.$$

(c) Bending of Levers.

Let P = load at "light" end of levers = 15,000 pounds.

l = length middle knife edge to light knife edge =

45 inches for front, 86.67 inches for back.

E = modulus of elasticity = 30,000,000.

I = moment of inertia at middle knife edge.

δ = deflection at middle knife edge.

Mr. H. J. Moore gives $\delta = 0.22 \frac{Pl^3}{EI}$ for deflection at middle knife edge as determined by himself and Mr. E. P. Burton.

By this formula for front lever,

$$\delta = \frac{(.22)(15,000)(45)^3}{(30,000,000)(322)} = .031.$$

For back lever,

$$\delta = \frac{(.22)(15,000)(86.67)^3}{(30,000,000)(1194)} = .060.$$

$$\text{Average deflection} = \frac{.031 + .069}{2} = .0455.$$

Total deflection due to (a), (b) and (c),

$$= .0743 + .0092 + .0455 = .1290.$$

Energy.

Let P = maximum force = 600,000 pounds.

S = total movement = .1290.

E = energy stored in inch pounds = $\frac{PS}{2} =$
 $\frac{(600,000)(.1290)}{2} = 38,700$ inch pounds = 3225 foot
 pounds.

Without means of checking recoil this energy would be employed in lifting table and weighing columns and head into air and would be returned in form of a blow upon knife edges.

The weighing columns, table, and weighing head weigh about
 $3(3000) + 12,000 + 4000 = 25,000$ pounds.

38700 inch pounds would raise this $\frac{38700}{25000} = 1.548$ inches.

Let W = static value of load applied to member,

h = height from which W falls.

l = total distortion of member hit.

p = maximum intensity of resulting stress.

P = maximum resulting load.

d = deflection of member due to static load W .

$$x = \frac{h}{d}.$$

Then from John H. Barr's Notes on Machine Design,

$$W(h+l) = l/2Pl \quad \text{or} \quad P = \frac{2W(h+l)}{l}$$

$$\frac{l}{x} = \frac{P}{W} \quad \text{or} \quad l = \frac{Pd}{W}.$$

$$\text{Hence } P = \frac{2W\left(h + \frac{Pd}{W}\right)}{\frac{Pd}{W}} = \frac{2W^2h}{Pd} + 2W,$$

$$\text{or } P^2 = \frac{2W^2h}{d} + 2WP = 2W^2x + 2WP.$$

$$\text{Solving, } P = W(1 + \sqrt{1 + 2x})$$

$$d = .22 \frac{Pl^3}{EI} = \frac{.22 \frac{25,000}{4-x-10} (45)^3}{(30,000,000)(322)} = .0013 \text{ for front lever.}$$

$$d = \frac{(.22) \frac{25,000}{4-x-10} (86.67)^3}{(30,000,000)(1194)} = .0024 \text{ for back lever.}$$

$$\text{Average} = \frac{.0013 + .0024}{2} = .0019.$$

$$x = \frac{h}{d} = \frac{1.548}{.0019} = 815. \quad \text{should not include deflection of plunger weighing head and compression of column under their own weight}$$

$$\text{Hence } P = 25,000(1 + \sqrt{1 + 2(815)}) = (25,000)(41.4) = 1,035,000$$

or a pressure of 1,035,000 pounds on knife edges without any system to take care of recoil.

$$\text{This gives a pressure per lineal inch} = \frac{1,035,000}{4 \left(\frac{16+15 \frac{1}{2}}{2} \right)} =$$

16,400 which is too high.

The system used to dissipate energy of recoil is as follows:- Four cylinders eight inches in diameter are used which rest upon weighing table. In each works a plunger which is attached to a lug upon guide columns. Cylinder is filled with oil which is supplied from a tank at top of guide columns by suitable piping. Upon main supply pipe is a valve by means of which the size of an escape aperture may be regulated. Through this small opening the liquid is compelled to flow as table rises on recoil. The work done is thus diverted in a measure from raising the table and weighing columns and head and thus decreasing the resultant blow upon knife edges. It is presumed that the piston friction is slight and will not cause large error in weighing.

The recoil of levers at full load is 600,000 pounds and that of the weighing columns, head and table about the same, making a total load on cylinders of 1,200,000 pounds. The area of cylinders is $4(50.27) = 201$ square inches or approximately 200 square inches.

$$\text{Unit pressure} = \frac{1,200,000}{200} = 6000 \text{ pounds per square inch.}$$

Walls of cast steel two inches thick.

By Merriman,

$$S = \frac{r_2^2 + r_1^2}{r_2^2 - r_1^2} p_1$$

S = tangential stress in wall.

r_1 = inner radius = 4 inches.

r_2 = outer " = 6 "

p_1 = inner pressure = 6000 pounds per square inch.

$$\text{Hence } S = \frac{6^2 + 4^2}{6^2 - 4^2} (6000) = 15,600 \text{ pounds per square inch.}$$

If the 38,700 inch pounds are entirely dissipated the average pressure will be $\frac{6000}{2} = 3000$.

The amount of liquid that must be forced through aperture must be $\frac{38,700}{3000} = 12.90$ cubic inches.

If this takes place in two seconds the amount of water passed per second = $\frac{12.90}{2} = 6.45$ cubic inches per second.

$$Q = .97a\sqrt{2gh}$$

$$a = \frac{6.45}{1728} \cdot \frac{1}{.97 (2)(32.2)(6000)(2.3)} = .000004 \text{ square feet,}$$

$$= .0006 \text{ square inches.}$$

Needle valve is used.

Amount of deflection of levers was found to be .0455.

When table rises to resume original position there will be forced out, $(200)(.0455) = 9.10$ cubic inches of water and pressure will be,

$$\frac{12.90 - 9.10}{12.90} (6000) = 1770 \text{ pounds per square inch,}$$

and there will have been dissipated $\frac{6000 + 1770}{2} (9.1) = 35,350$ inch pounds., leaving $38,700 - 35,350 = 3350$ inch pounds to be used chiefly in lifting parts from levers.

Part however will be used in forcing a small additional quantity through needle valve.

3350 would raise 25,000 pounds 0.134 inches per hour

$$\frac{h}{d} \text{ (see p. 63)} = \frac{.134}{.0019} = 70.5.$$

$$\begin{aligned} \text{Hence } p &= 25,000(1 + \sqrt{1 + (2)(70.5)}) = 325,000 \text{ or a pressure} \\ \text{per lineal inch of } &\frac{325,000}{4\left(\frac{16 + 15 \frac{1}{2}}{2}\right)} = 5100 \text{ which is safe.} \end{aligned}$$

As to whether tank will keep cylinder full,

Head = 25 feet,

$$Q = .97a\sqrt{2gh}$$

$$= 1728(.97) \frac{.0006}{144} \sqrt{2(32.2)(25)} = .280 \text{ cubic inches}$$

per second.

Hence it would take $\frac{9.10}{.280} = 33$ seconds to fill up cylinder if application of load is uniform and there is no friction.

VIII.

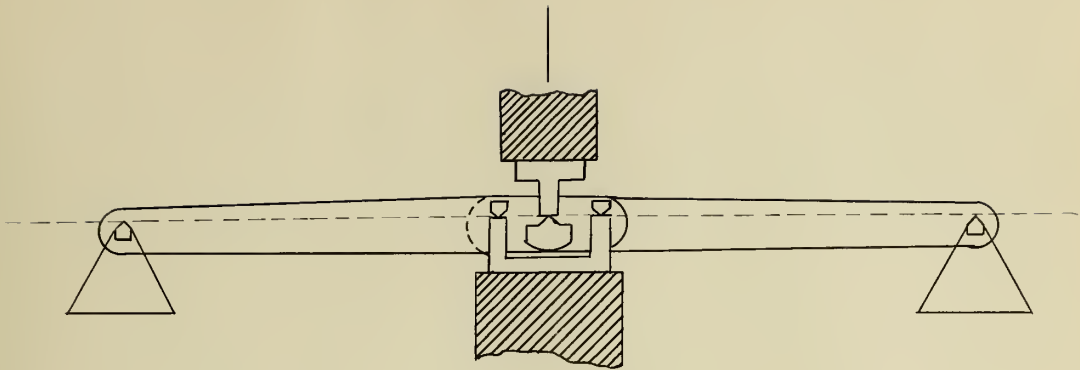
CALIBRATION.

According to the contract and specifications the machine was to be calibrated at the works of the company and also at the University after being set in place. The plan of calibration was first to calibrate up to one tenth of the capacity of the machine, 600,000 pounds, by means of calibrating levers and dead weight, using both small and large poise; and second, to calibrate from 60,000 pounds to 600,000 pounds by means of a calibrating bar and extensometer to be furnished by the University.

The calibration has been divided, somewhat arbitrarily, into seven parts which will be taken up separately. The data for these tests and the curves plotted are on succeeding pages.

Test No. 1.

Riehle calibrating levers with a count of ten were used. The arrangement of levers is shown in figure on the following page. The small poise was used. As weights, 1000 pounds in standard weights and 5000 pounds of pig iron were used. The pig iron was divided into two lots of 2000 pounds each and one lot of 1000 pounds. The standard weights consisted of twenty weighing 50 pounds each. By the proper combinations, loads on bales of levers, ranging by even hundreds up to 6000 pounds were secured or the equivalent to loads on table up to



60,000 pounds by even thousand pounds.

After the loading reached 20,000 pounds the hydraulic cylinders were tapped smartly with a hammer after each preliminary reading and a second reading was then taken as is seen from the table, the beam generally showed a slight increase in load as a result of this tapping. The waviness of the curve seems to show that there was a slight friction or binding action in the cylinders and that the tapping relieved this by jerks.

Two incidents of the test which are noteworthy are the sensitiveness indicated by the movement of the needle beam, 1/16 inches by the addition of a weight of 8 1/2 pounds at a load of 60,000 pounds, and the accuracy with which the person standing on the table was weighed under same load.

This test indicates that the poise is about 0.7 percent light.

Test No. 2.

The methods used were the same as in test above.

In (a) and (d) the calibrating levers were used and loads put on by increments of 1000 pounds up to 6000 pounds. In (b) and (c) loads were dead weight on table by same increment. The results indicate, in general, that the poise is light, within this range, about one-half of one percent.

Test No. 3.

This test is in five parts, in all of which except (c) the load increases by increments of 10,000 pounds up to 60,000 pounds. In (c) the load increases by 1000 pound increments up to 6000 pounds. The large poise is used in first two parts and small poise in the remaining parts. After (a) the recoil cylinders were removed and left off for the remainder of the calibration, this being deemed advisable from the results of Tests Nos. 1 and 2. This test indicates that large poise is light by 0.7 to 0.8 percent while small poise is in error in same direction by a slightly smaller percent.

Test No. 4.

Small poise was corrected by adding 31 grams of lead. The center of gravity was determined by balancing latter on knife edge and lead was then added as near as possible to this. 31 grams is 0.65 percent of the weight of the poise which is 10.4 pounds.

Large poise was also corrected in same manner by the addition of 341 grams which is 0.7 percent of its weight which is 104 pounds.





Same tests were repeated as in Test No. 3. Results show that small poise is correct to within less than 0.1 percent while large poise was now slightly heavy consequently 58 grams of lead was removed, leaving 283 grams as amount added during test. This is 0.6 percent of weight of poise. Test was then repeated and results show that large poise, also, is correct to within much less than 0.1 percent. This completes the calibration below 60,000 pounds.

Test No. 5.

Removed calibrating levers, put calibrating bar in place, and attached extensometer. The arrangement is quite well shown in accompanying photographs.

The calibrating bar is of annealed nickel steel about 19 feet 6 inches in length and 4.0089 inches in diameter. The greatest variation from this is 0.0006 inches and occurs at but one place. The average variation from mean for twelve sections is 0.00018 inches. A physical test of two samples of steel from which bar was made is given below. The nuts at end of bar were supported upon spherical seats.

The extensometer was used with a distance between bearings of 144 inches. Springs held the bar against roller.

In this test loads were put on up to 60,000 pounds in (a), (b) and (c), and up to 100,000 pounds in part (d). The results are most consistent in (c). The average elongation here is 0.0381 inches for 100,000 pounds which gives a coefficient of elasticity of 30,100,000 pounds per square inch.

Record of Test of Pieces from Calibrating Bar
for 600,000 lb. Machine.

Mark	82710-3	82710-1
Diameter in inches	.508	.508
Area in square inches	.2026	.2026
Load, at Elastic Limit	12700	13000
Elastic Limit, lbs./sq. in.	62100	64100
Maximum Load, lbs.	19000	19800
Ultimate Strength, lbs./sq.in.	93700	97700
Elongation in 2 inches.	.53	.47
Percent Elongation in 2 inches.	26.5	23.5
Diameter of Reduced Section.	.308	.315
Area of Reduced Section.	.0745	.0779
Reduction in Area	.1281	.1247
Percent Reduction in Area	63	62

May 1, 1905.

R. H. Slocum.

Test No. 6.

With increments of 10,000 pounds, put load on up to 500,000 pounds. Used a time interval of 2.5 minutes between time load was on and final reading.

The result are not very consistent throughout, the large variations being due, for most part, to the failure of extensometers to act properly.

Test No. 7.

In this test the extensometer springs were stiffened by the addition of rubber bands and much more satisfactory results were obtained. From parts (b) and (c) the average "mean" elongation per 100,000 pounds are 0.03823 inches and 0.03818 inches respectively. These give coefficients of elasticity of 30,200,000 and 30,160,000 pounds per square inch. This is 0.33 and 0.20 percent higher than for below 60,000 pounds as found in Test No. 5.

Conclusion.

From, lack of time it was found impossible, ^{now} to obtain completely satisfactory and thorough results on the calibration, the principal difficulty encountered being in the performance of the extensometer. The most consistent results were secured when springs were stiffened as in Test No. 7 and it seems that some similar method must be adopted before a more thorough calibration can be accomplished.

IX.

SPECIFICATION TESTS.

Seven tests are included here which are to try the machine as to recoil, eccentric loading, and power required to operate. These tests will be taken up in order. Data will be found on succeeding pages.

Test No. 8.

This test was made as a preliminary to Test No. 9. The stretch of screws was measured by measuring clearance at top of same. The jump of weighing head was obtained by inserting a wooden wedge between weighing head and cross head of weighing columns. On recoil the amount of jump of head was given by amount of crushing of wedge. Observer was seated on top of machine at failure of specimen. No perceptible jump of machine was noted but merely a heavy quiver.

Test No. 9.

This is the same test as no. 8 with a larger piece and that of cast iron instead of steel. The object was to get as large recoil as possible. The jump of weighing head was quite large but this is not especially objectionable except for the amount of pounding, or impact, which it will give on falling back. The pulling head did not jump an amount sufficient to be measured by means of the apparatus used which consisted merely of a plank thrown between weighing columns with a peg

in same which was brought in contact with lower side of head and which could slide easily under pressure of head.

Test No. 10.

This test was to measure the effect of the maximum eccentric loading. The deflection of guide columns was obtained as follows:- Heavy thread was fixed to the lower chords of the two middle roof trusses and carried in a north and south direction across the tops of guide columns within say one-quarter of an inch of their top surfaces. One thread was used for the east column and one for the west. Planks were thrown between roof trusses at each side of machine and threads in an east and west direction were fixed as before. Punch marks on top of column indicated by their movement with respect to the thread the movement of top of the guide columns. The deflection of weighing columns was obtained as follows:- Wooden pointers about eight feet long were weighted to the cross head of the columns, one pointer east and west and one pointer north and south. The movements of the ends of these pointers with respect to fixed points was then observed. The calculated deflection for load of 300,000 pounds is $\frac{2.29}{2} = 1.15$ inches (see computations). Actual deflection in this case is 0.71 inches or about 62 percent of the theoretical. Inclination of column to secure eccentric loading was obtained by the use of wedge shaped blocks at both ends.

Test No. 11.

This is the same as Test No. 10 except that column was put in plane at right angles to that of screws. As was to be expected the deflection was reduced and taking place in both directions. Deflections are, however, very small in amount.

Test No. 12.

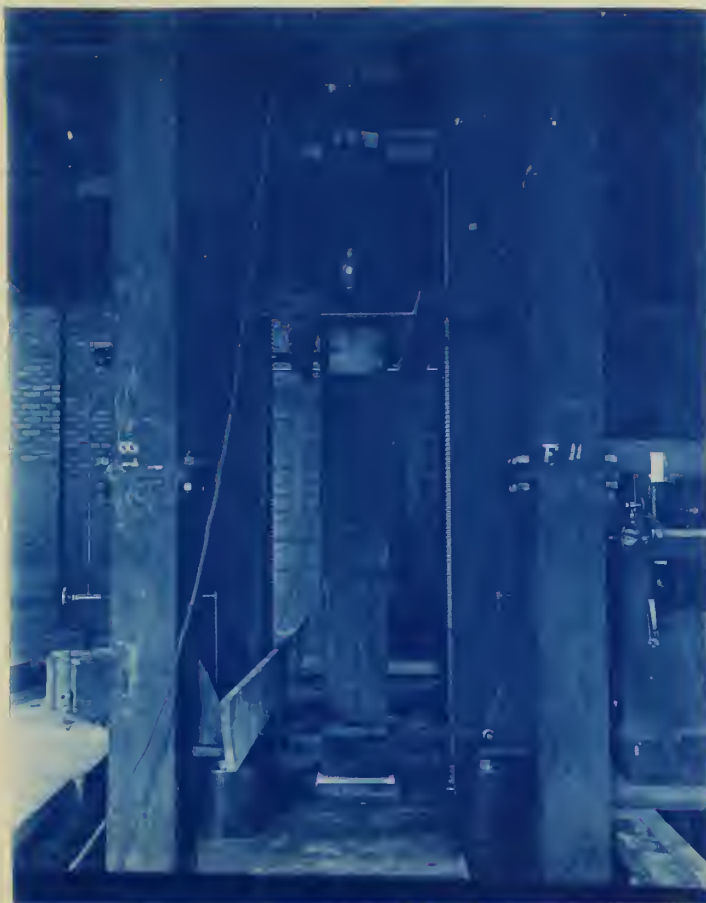
In this test wooden columns were substituted for cast iron columns of Tests Nos. 10 and 11. Eccentricity of 5 inches was all put at bottom. The deflection at 400,000 pounds load is 0.83 inches as against $(2/3)(2.29) = 1.53$ inches. This is 54 percent. It was discovered in this test that there was insufficient clearance between flanges of weighing columns and pulling head. These came in contact with the load of 400,000 pounds. For maximum load and this eccentricity it will be necessary to increase normal clearance which will probably be effected by the removal of from an inch to an inch and a half from the flanges of the columns. Part of the apparent deflection of weighing columns is no doubt caused by the slight difference in deflection of main levers due to the 5 inches of eccentricity. Wooden wedges were used to give eccentricity to the column.

Test No. 13.

This is the same as No. 12 with plane of eccentric loading at right angles to plane of screws and with the eccentricity divided equally between top and bottom. The greatest deflection of guide columns is 0.28E(ar right angles to plane

of screws). Column buckled under load of 500,000 pounds in plane parallel to that of screws. It is probable that load was not evenly distributed between the two beams composing the columns as one was about two inches shorter than the other and the block used as filler indicated a compression of about one-fourth inch.

Photograph accompanying shows arrangement.



Test No. 14.

Watt meters were connected to the two circuits and observations taken of power used during Test No. 12 with load applied at different rates of speed. The results show that the motor used has an excess of horse-power which, however, is not ^{so} too large to be undesirable.

Conclusion.

The tests show that machine behaves satisfactorily under eccentric loading as far as expected deflections are concerned. The lack of clearance between weighing columns is serious, how^ever, and must be corrected before tests can be made up to full capacity at maximum eccentricity.

X.

CONCLUSIONS.

The history of the testing machine industry has been briefly discussed, the types of machines now in use were described, a few particular machines were described, and the qualities which a testing machine should possess were given. These things were done that a better idea might be had of the condition of testing machine development and of what might be expected at the present time in a testing machine.

The plans proposed for the machine under discussion were described briefly and the machine as adopted more thoroughly. The efficiency of the main features of its design were reviewed and the work of the machine as it showed up in the calibration and other tests was given.

The results of the tests meet the specifications. The sensitiveness of the machine is very much greater than expected; the accurate response of the weighing mechanism to small increments of load at all points within limits of capacity is especially noticeable; the accuracy of the scale beam below one tenth of the capacity is much beyond specification requirements; and the accuracy of the beam for the upper range of the capacity is at least partially established although it were better that further investigation be made as to this with the improvement in extensometer apparatus which was found to be necessary.

The design of the machine, in general, seems to solve

the problems which arise here as peculiar to the requirements necessitated by the capacity of the machine and the size of specimens to be used.

XI.

CHRONOLOGY.1905

- April 7. Three cars received containing bed plate, columns, heads, table, cover plate, and screws.
- " 9. Sunday.
- " 10. Bed plate set in afternoon. Fourth and last car received.
- " 11. Front and back legs were placed in afternoon and main bracket lowered but not placed.
- " 12. Main bracket placed and wedged up. Shaft pedestal and bed plate for motor put in position. Mr. W. C. DuComb, Engineer for Riehle Bros. took charge in morning.
- " 13. Gearing put in and cover plate started.
- " 14. Cover plate lowered by jacks and cribs and all levers put in place. Crib fixed for weighing table.
- " 15. Weighing table lowered upon knife edges. Two heads placed upon top of weighing table. Lower section of one guide column placed.
- " 16. Sunday.
- " 17. Remaining first sections of guide columns placed and hole cut in floor of second story.
- " 18. Preparations made to raise screws.
- " 19-22. Screws raised and weighing columns placed.
- " 23. Sunday.

- April 24. Guide columns finished.
- " 27. Guides put on for screws, also tank for recoil cylinders.
- " 28. Full load run on for first time--compression of tools.
- " 29. Tightening nuts and adjusting parts.
- " 30. Sunday.
- May 1. Calibration and tests begun.
- " 16. Finished same.
- " 17-19. All details finished and on latter date Mr. Du Comb left.

XII. Tables.

Test No.1.

Used Riehle Calibration Levers, and Small Poise.

May 1, 1905.

Load lbs.	Reading lbs.	Amount + or - lbs.	Percent + or -	Time	Remarks
0	0	0	0.00	A.M. 11:40	Temperature 62 degrees F.
1000	100 7	7	.7		
2000	20 20	20	1.0		
3000	30 30	30	1.0		
4000	40 25	25	.63		
5000	50 30	30	.6		
6000	60 35	35	.58		
7000	70 35	35	.5		
8000	80 35	35	.44		
9000	90 40	40	.44	P.M.	
10000	(100 45 (1000 5	45 5	.45 .05	12:10 1:50	Temperature 62 degrees F.
11000	110 35	35	.32		
12000	120 10	10	.08		
13000	130 45	45	.35		
14000	140 63	63	.45		
15000	150 40	40	.27		
16000	160 10	10	.06		
17000	170 25	25	.15		
18000	180 10	10	.06		
19000	190 15	15	.08		
20000	(200 30 (200 10	30 10	.15 .05	2:20 2:40	

Test No. 1 - continued.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - .	Remarks
	Before Tapping lbs.	After Tapping lbs.			
21000	21020	(21075 (21070	75 in 5 min.	0.36	Cylinders tapped after load applied and second reading taken.
22000	22100				
23000	23040	23125	125	.54	
24000	24130	24120	120	.50	
25000	25120	25125	125	.50	
26000	26095	26130	130	.50	
27000	27100	27140	140	.53	With no load on table,
28000	28125	28155	155	.55	Adding 10# moves needle beam
29000	29140	29155	155	.53	1/16" to 1/8".
30000	30125	30165	165	.55	4:20 P.M. Temp. 68°.
31000	31150	31210	210	.71	Setting at zero from -10 and
32000	32180	32230	230	.72	10 makes about 1/16" dif-
33000	33220	33230	230	.70	ference in pointer.
34000	34240	34240	240	.71	
35000	35245	35245	245	.70	
36000	36240	36260	260	.72	
37000	37240	37265	265	.72	
38000	38245	38265	265	.70	
39000	39265	39275	275	.71	
40000	40265	(40290 (40270	290	.73	5:38 P.M. Temp. 69°F.
					7:10 " " "
41000	41245	41325	325	.79	
42000	42320	42315	315	.75	7:45 P.M.

Test No. 1 - continued.

May 1, 1905.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
43000	43300	43295	295	0.69	Temp. 68° F.
44000	44320	44320	320	.73	
45000	45325	45325	325	.72	
46000	46325	46325	325	.71	
47000	47330	47330	330	.70	
48000	(48325 (48350 48360	350 More tapping	.73	
49000	49365	49380	380	.77	
50000	50375	50385	385	.77	
51000	51355	51385	385	.75	
52000	52375	52385	385	.74	
53000	53410	53385	385	.73	50# increase in load made 50# on beam before and after tapping.
54000	54410	54410	410	.76	
55000	55440	55415	415	.75	10:42 P.M. 8 1/2# weight moved beam 1/16". Temp. 65°. Weighed a man as 145#. Weight on scales = 146 1/2#. *May 2, 1905. Temp. 64°. 8:15 A.M.
56000	56440	56415	415	.74	
57000	57420	57440	440	.77	
58000	58440	58440	440	.76	
59000	59440	59550	550	.93	
60000	60450	60475	475	.79	
60000	60470*				
50000	50390				
40000	40295				
40000	40325				
50000	50385	50385	385	.77	Substituted weights.

Test No. 1 - continued.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
40000	(40 325 (40 295	40 295	295	0.74	Substituted weights.
30000	(30 235 (30 240 30 235	240 in 5 min.	.80	1000#(sealed) agreed to same on scales to 1/8#.
30000	30 205	30 220	220	.73	Substituted weights.
20000	(20 145 (20 095	20 150 20 125	150 125	.75 .63	Substituted weights.
10000	100 40	100 25	25	.25	Found weights 3# in excess = 30# load.
9000	90 40	90 25	25	.28	Temp. 67°.
8000	80 20	80 10	10	.13	
7000	70 35	70 10	10	.14	
6000	60 20	60 05	5	.08	
5000	50 10	50 00	0	.00	
4000	40 00	39 85	- 15	-.38	
3000	29 85	29 60	- 20	-.67	
2000	20 10	19 65	- 35	- 1.75	
1000	9 75	9 55	- 45	- 4.50	
0	-025	-015	-015		Temp. 69°.

Test No. 2.

(a) Using Calibrating Levers.

May 2, 1905.

Load lbs.	Reading		Amount + or - lbs	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
0	- 020				11:34 A.M.
1000	970	1000	20	2.0	11:39 "
2000	1980	1985	5	.25	11:43 "
3000	2995	2995	15	.50	11:46 "
4000	3975	4010	30	.75	11:49 "
5000	5000	5000	20	.40	11:52 "
6000	6005	6010	10	.17	11:55 "
3000	3010	2990	10	.33	
			15(2d zero).	.50	
0	- 015	- 025	- 5		12:10 P.M. Temp. 69°.
(b) Using Dead Weight on Table.					
0	095	125			1:12 P.M. Temp. 70°.
1000	1100	1125	30	3.00	1:35 "
0	(115	115			
	(120			1:47 "
2000	2140	2125	5	0.25	
3000	3145	3130	10	.33	2:17 "
5000	5090	5070	- 50	- 1.00	
			5(2d zero).	.10	
6000	6115	6075	- 45	- .75	2:52 P.M.
			10(2d zero).	.17	
0	045	065	- 55		
2000	2075	2080	15	.75	3:35 P.M. Temp. 72°.
Adjusted calibration levers and other knife edges.					
2000	1925	1945			

Test No. 2.

(c) Using Dead Weights on Table.

May 2, 1905.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
	Movement of 10 pounds on dial (small poise) moved needle beam 1/8".				
1000	10 15	(10 20 (10 15	10 2		
0	(-0 15 (0	0 10 - 0 05			5:33 P.M. Temp. 72° F. 7:23 " " 70° F.
1000	10 25	9 95	0	0.00	
0	-0 05	- 0 10	-0 05		
2000	20 30	20 00	10	.50	
3000	30 30	29 95	5	.17	
4000	40 20	40 10	20	.50	
5000	50 35	49 85	- 5	- .10	
6000	60 45	60 15	25	.43	
3000	30 25	30 00	10 - 15 (2d zero)	.33 - .50	9:05 P.M.
(d) Using Calibrating Levers.					
0	- 0 25	0 15	25		
1000	9 90	10 10	- 5	-.50	
2000	20 00	20 10	- 5	-.25	
3000	30 05	30 15	0	.00	
4000	40 15	40 10	- 5	-.13	
5000	50 20	50 35	20	.40	
6000	60 00	60 45	30	.50	
3000	30 65	30 15	0	.00	9:53 P.M.
0	{ 0 60 15	- 10 15	-25 - 5 0		10:03 P.M. Temp 70°.

Test No. 3.

(a) Large Poise. Calibrating Levers.

May 3, 1905.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
0		015			7:55 P.M. Temp. 72°. Small poise.
	50 lbs. on beam moves needle beam 7 - 1/8" sps.				
0		0			Large poise used from here on.
10000	10050	10100	100	1.00	8:23 A.M.
20000	20150	20150	150	0.75	
30000	30175	30225	225	.75	
40000	40250	40250	250	.63	
50000	50375	50375	375	.75	8:57 A.M.
60000	60475	60525	525	.88	9:03 "
30000	30225	30250	250	.83	9:19 "
0	050	0	0		9:28 "
(b) Cylinders removed. Using large poise.					
	50 lbs. on beam gives 8 - 1/8" sps.-needle beam.				
0	400				10:10 A.M.
10000	10525		125	1.25	Temp. 76°.
20000	20600		200	1.00	
30000	30650		250	.83	
40000	40700		300	.75	
50000	50750		350	.70	
60000	60925		525	.88	
30000	30675		275	.92	
0	400		0		11:07 A.M. Temp. 76°.

Test No. 3.

(c) Using Small Poise, Cylinders Still Off.
May 3, 1905.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
0	0				11:22 A.M.
1000	1007		7	0.7	
2000	1985		- 15	- .75	
1000	985		- 15	- 1.5	11:30 A.M.
0	005	readjusted			
1000	1010		5	.50	
2000	2015		10	.50	
3000	3015		10	.33	
4000	4015		10	.25	
5000	5015		10	.20	
6000	6035		30	.50	11:58 A.M.
3000	3015		10	.33	12:01 P.M.
			15 (2d zero)	.50	
0	0		- 5		12:07 " Temp. 77°.
(d) Same Conditions as (c).					
0	- 010				1:25 P.M. Temp. 77°.
10000	10040		50	.50	
20000	20120		120	.60	
30000	30120	*	190	.63	
40000	40215		285	.71	
50000	50285		355	.71	
60000	60375		445	.74	2:18 P.M.

* From here on it is evident that 2d zero should be used.

Test No. 3. (d) continued.

Load lbs.	Reading		Amount + or - lbs.	Percent + or - %	Remarks
	Before Tapping lbs.	After Tapping lbs.			
50000	50 295		365	0.73	
40000	40 215		285	.71	
30000	30 215		285	.95	
20000	20 070		140	.70	
10000	10 005		75	.75	
1000	9 40		10	1.00	
500	4 40		10	2.00	
50	-20		0	0	2:55 P.M. May 3, 1905.
(e) 0	-70	Estimated from	reading	above	
10000	9980		50	.50	
20000	20 065		135	.68	
30000	30 125		195	.65	
40000	40 210		280	.70	
50000	50 265		335	.67	
60000	60 250		320	.53	4:01 P.M.
50000	50 265		335	.67	
		(2d zero)	355	.71	
40000	40 210		280	.70	
		(2d zero)	300	.75	
30000	30 110		180	.60	
		(2d zero)	200	.67	
20000	20 045		115	.58	
		(2d zero)	135	.68	
10000	9970		40	.40	4:40 P.M.
		(2d zero)	60	.60	
100	0 10		-20	-20.0	
		(2d zero)	0	0	
0	- 90		-20	Estimated from above reading.	

Test No. 4.

(a) Cylinders off. Small poise readjusted.
May 3, 1905.

Load lbs.	Reading lbs.	Amount + or - lbs.	Percent + or -	Remarks
Added 31 g. lead to small poise in center hole as near center of gravity as possible. 31 g. = 0.6 1/2% of weight of poise, 10.4 lbs.				
0	0			
10000	10000	0	0	7:22 P.M.
20000	19990	- 10	-0.05	
30000	29995	- 5	- .02	
40000	40010	10	.03	
50000	49990	- 10	- .02	
60000	60020	20	.03	8:01 P.M.
50000	50015	15	.03	
		* 0	.00	
40000	40010	10	.03	
		*- 5	- .01	
30000	30010	10	.03	
		*- 5	- .02	
20000	20015	10	.08	
		* 0	.00	
10000	10000	0	.00	
		*-15	- .15	
(b) 0	015	15		8:38 P.M. Temp. 76°.
100	125	10	10.0	
1000	1015	0	0.0	
2000	2015	0	.0	
3000	3015	0	.0	
4000	4015	0	.0	
5000	5005	- 10	- .2	
6000	6000	- 15	- .25	9:06 P.M.
3000	3015	0	.0	
		* 5	.17	
0	10	- 5		9:14 P.M.
* Second zero.				

Test No. 4.

(c) Large poise readjusted same way as small poise.
Amount added = 341 grams.

May 3, 1905.

Load lbs.	Reading lbs.	Amount + or - lbs.	Percent + or - %	Remarks
0	0			10:00 P.M.
10000	10000	0	0.0	
20000	19950	- 50	- .25	
30000	29900	- 100	- .33	
40000	39900	- 100	- .25	
50000	49925	- 75	- .15	
60000	59975	- 25	- .04	10:30 P.M.
30000	29900	- 100	- .33	
0	0	0		10:46 P.M. Temp. 75°.
(d) Same as (c).				May 4, 1905.
0	0			8:45 A.M.
10000	10025	25	0.25	Temp. 74°.
20000	19950	- 50	- .25	
30000	29900	-100	- .33	
40000	39900	-100	- .25	
50000	49925	- 75	- .15	
60000	59950	- 50	- .08	9:18 P.M.
50000	49925	- 75	- .15	
30000	29900	-100	- .33	
0	0	0		9:39 P.M. Temp. 75°.

Test No. 4.

(e) Large poise corrected second time by taking away 58 g. leaving amount added = $341 - 58 = 283$ g.

May 4, 1905.

Load lbs.	Reading lbs.	Amount + or - lbs.	Percent + or - 1.	Remarks
0	0	0		11:10 A.M. Temp. 75°.
10000	10000	0	0.0	
20000	20000	0	.0	
30000	30025	25	.08	
40000	40000	0	.00	
50000	49950	- 50	- .10	
60000	60000	0	.00	11:42 A.M.
50000	49950	- 50	- .10	
30000	30025	25	.08	11:52 A.M.
0	0	0		Temp. 75°.

Test No. 5.

Using Calibrating Bar.

May 5, 1905.

Initial Load = 1000 lbs.

Load lbs.	Extensometer		Increments		Mean	per 100,000#	
	#1	#2	#1	#2			
0	0.4996	0.4994	.	.			
30000	.0101	.0112	0.0105	0.0118	0.0112	0.0373	11:23 A.M.
60000	.0185	.0232	.0084	.0120	.0102	.0340	
60050							12:07 A.M.

Very much vibration of specimen and parts of machine when motor was running. Blocked machine girders by 4" x 4" against walls of pit.

Test No. 5. con.

Load lbs.	Reading		Increment		Per 100000 lbs.		Mean	Remarks
	#1	#2	#1	#2	#1	#2		
(a) 0	.0614	.1112						3:25 P.M. May 5, 1905. Temp. 71°.
0	.0611	.1111						
50	.0611	.1111						
30000	.0719	.1228						
	.0722	.1231						
	.0723	.1231	.0112	.0120	.0373	.0400	.0387	
60000	.0834	.1342						
	.0832	.1341						
	.0831	.1339	.0108	.0108	.0360	.0360	.0360	4:02 P.M.
30000	.0711	.1228						
	.0711	.1228						
	.0713	.1229	.0118	.0110	.0393	.0367	.0380	
0	.0606	.1108						
	.0604	.1106						
	.0603	.1105						
	.0591	.1094	.0122	.0135	.0407	.0450	.0430	5:16 P.M. Tem. 72°
(b) 0	.0591	.1088						7:46 "
10200	.0630	.1130	.0039	.0042	.0382	.0412	.0397	
20500	.0667	.1169	.0037	.0039	.0359	.0379	.0369	
30900	.0706	.1210	.0039	.0041	.0375	.0394	.0385	
39850	.0740	.1246	.0034	.0036	.0380	.0402	.0391	
51200	.0785	.1292	.0045	.0046	.0333	.0341	.0337	
60000	.0820	.1326	.0035	.0034	.0398	.0386	.0392	8:03 P.M.
20000	.0666	.1178	.0154	.0148	.0385	.0370	.0378	
31100	.0712	.1218	.0046	.0040	.0418	.0364	.0391	
From 60,000 lbs.			.0108	.0108	.0374	.0374	.0374	
-1000	.0595	.1095						
0	.0600	.1097	.0112	.0121	.0360	.0390	.0375	8:16 P.M.

Test No. 5. (c)
Initial Load = 2000 lbs. May 5, 1905.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
0	.0603	.1100						8:24.5 P.M.
10500	.0642	.1141	.0039	.0041	.0371	.0391	.0381	
19900	.0676	.1177	.0034	.0036	.0362	.0383	.0373	
30150	.0714	.1217	.0038	.0040	.0371	.0390	.0381	
41000	.0755	.1260	.0041	.0043	.0378	.0396	.0387	
50900	.0793	.1299	.0038	.0039	.0384	.0394	.0389	
60100	.0828	.1333	.0035	.0034	.0380	.0370	.0375	8:41 P.M.
27200	.0699	.1213						
29900	.0710	.1221	.0118	.0112	.0391	.0371	.0361	
-1000	.0602	.1104						
(d) 0	.0608	.1107	.0102	.0114	.0375	.0419	.0397	8:57 P.M.
9900	.0640	.1142	.0032	.0035	.0323	.0353	.0338	
19900	.0670	.1176	.0030	.0034	.0300	.0340	.0320	
30550	.0714	.1220	.0044	.0044	.0413	.0413	.0413	
40000	.0750	.1257	.0036	.0037	.0381	.0392	.0386	
49900	.0786	.1295	.0036	.0038	.0364	.0384	.0374	5 1/2 min. interval.
60300	.0828	.1335	.0042	.0040	.0404	.0385	.0395	
70300	.0865	.1373	.0037	.0038	.0370	.0380	.0375	
80100	.0901	.1410	.0036	.0037	.0367	.0377	.0372	
90000	.0937	.1447	.0036	.0037	.0364	.0374	.0369	5 1/2 min. interval
100100	.0970	.1486	.0033	.0039	.0327	.0387	.0357	10:03 1/2 P.M.
89900	.0932	.1451	.0038	.0035	.0372	.0343	.0358	5 1/2 min. int 'v' 1
80100	.0887	.1415	.0045	.0036	.0460	.0367		do
70100	.0848	.1377	.0039	.0038	.0390	.0380	.0385	do

Test No. 5.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
60000	.0810	.1339	.0038	.0038	.0376	.0376	.0376	5 1/2 min.int'v'l
50500	.0775	.1305	.0035	.0034	.0368	.0358	.0363	do
41000	.0740	.1270	.0035	.0035	.0368	.0368	.0368	do
30100	.0701	.1231	.0039	.0039	.0358	.0358	.0358	do
20250	.0665	.1191	.0036	.0040	.0365	.0406	.0385	7 1/2 min.int'v'l
10350	.0632	.1148	.0032	.0043	.0323	.0434	.0379	5 1/2 " "
100	.0598	.1108	.0035	.0040	.0341	.0390	.0366	11:22 P.M.
- 350	.0618	.1129						7:55 A.M. May6th.

Test No. 6.

May 6, 1905.

- 350	.0622	.1133						Temp. 71°. 9:24 A.M.
9750	.0662	.1175	.0040	.0042	.0396	.0416	.0406	2 1/2 min.int'v'l
19950	.0699	.1217	.0037	.0042	.0363	.0412	.0387	do
30000	.0735	.1255	.0036	.0038	.0358	.0378	.0368	do
39850	.0770	.1291	.0035	.0036	.0355	.0365	.0360	do
50250	.0809	.1331	.0039	.0040	.0375	.0385	.0380	do
60150	.0847	.1370	.0038	.0039	.0376	.0386	.0381	do
70000	.0885	.1407	.0038	.0037	.0374	.0364	.0369	do
80100	.0920	.1443	.0035	.0036	.0346	.0356	.0351	do
90000	.0954	.1480	.0034	.0037	.0344	.0374	.0359	do
100100	.0986	.1520	.0032	.0040	.0317	.0396	.0357	do
109750	.1020	.1557	.0034	.0037	.0352	.0384	.0368	
Began to drop off here during interval. standing.								
120000	.1059	.1599	.0039	.0042	.0381	.0410	.0395	3 min. interval.
129800	.1091	.1638	.0032	.0039	.0326	.0398	.0362	2 1/2 min. "
139450	.1121	.1673	.0030	.0035	.0310	.0362	.0336	" " "

Test No. 6.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
149900	.1150	.1710	.0029	.0037	.0278	.0354		2 1/2 min.int'v'l
159600	.1181	.1741	.0031	.0031	.0320	.0320	.0320	do
169650	.1225	.1783	.0044	.0042	.0438	.0418	.0428	do
180200	.1267	.1826	.0042	.0043	.0398	.0408	.0403	do
189550	.1298	.1858	.0031	.0032	.0330	.0341	.0336	do
199500	.1333	.1895	.0035	.0037	.0352	.0372	.0362	10:27 A.M. do
209550	.1364	.1932	.0031	.0037	.0308	.0368	.0338	do
219500	.1398	.1969	.0034	.0037	.0342	.0372	.0357	do
229300	.1432	.2006	.0034	.0037	.0347	.0377	.0362	do
239600	.1465	.2044	.0033	.0038	.0320	.0369	.0345	do
249650	.1505	.2091	.0040	.0047	.0398	.0467	.0435	
259300	.1540	.2132	.0035	.0041	.0338	.0396	.0367	
269600	.1580	.2173	.0040	.0041	.0388	.0398	.0393	
279600	.1613	.2209	.0033	.0036	.0330	.0360	.0345	
	Slight vibration of extensometer indicators.							
289900	.1641	.2250	.0028	.0041	.0272	.0398	.0335	
299300	.1679	.2288	.0038	.0038	.0404	.0404	.0404	10:58 A.M.
309600	.1717	.2328	.0038	.0040	.0369	.0388	.0379	
319800	.1755	.2368	.0038	.0040	.0372	.0392	.0382	
329350	.1794	.2409	.0039	.0041	.0408	.0430	.0419	2 1/2 min. int.
339200	.1827	.2440	.0033	.0031	.0335	.0315	.0325	
349300	.1862	.2477	.0035	.0037	.0346	.0366	.0356	
359600	.1890	.2516	.0028	.0039	.0272	.0378		
369400	.1927	.2555	.0037	.0039	.0377	.0398	.0389	
382000	.1967	.2602	.0040	.0047	.0318	.0373	.0346	
389250	.1996	.2631	.0029	.0029	.0400	.0400	.0400	

Test No. 6.

May 6, 1905.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
399300	.2035	.2670	.0039	.0039	.0388	.0388	.0388	11:29 A.M. 2 1/2 min. int.
409900	.2075	.2708	.0040	.0038	.0376	.0356	.0366	
419000	.2099	.2736	.0024	.0028	.0264	.0308		
428700	.2140	.2766	.0041	.0030	.0422	.0309	.0368	
438900	.2169	.2796	.0029	.0030	.0285	.0294	.0290	
449200	.2203	.2830	.0034	.0034	.0330	.0330	.0330	
459000	.2241	.2863	.0038	.0033	.0388	.0337	.0363	
468700	.2281	.2901	.0040	.0038	.0412	.0391	.0401	
478700	.2317	.2942	.0036	.0041	.0360	.0410	.0385	
488800	.2357	.2981	.0040	.0039	.0396	.0386	.0391	
498700	.2399	.3020	.0042	.0039	.0424	.0394	.0409	11:59 A.M.
490500	.2366	.2990	.0033	.0030	.0402	.0366	.0384	12:05 1/2 P.M.
479900	.2327	.2949	.0039	.0041	.0368	.0387	.0378	2 1/2 min. int. 3 min. interval
470500	.2288	.2908	.0039	.0041	.0415	.0436	.0426	2 1/2 min. "
460000	.2248	.2866	.0040	.0042	.0381	.0401	.0391	" " "
450700	.2215	.2831	.0033	.0035	.0355	.0376	.0367	2 min. interval
440600	.2178	.2792	.0037	.0039	.0366	.0386	.0376	1 1/2 min. "
430300	.2139	.2753	.0039	.0039	.0378	.0378	.0378	2 min. interval
420500	.2103	.2716	.0036	.0037	.0367	.0377	.0372	" "
411100	.2067	.2679	.0036	.0037	.0383	.0384	.0388	
401100	.2033	.2643	.0034	.0036	.0340	.0360	.0350	12:35 P.M.
391700	.2004	.2609	.0029	.0034	.0309	.0362	.0336	
380800	.1970	.2568	.0034	.0041	.0312	.0376	.0344	
371000	.1937	.2531	.0033	.0037	.0337	.0377	.0357	
360500	.1899	.2492	.0038	.0039	.0362	.0371	.0367	

Test No. 6.

May 6, 1905.

Load lbs	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
350 700	.1863	.2452	.00 36	.00 42	.0 367	.0 428	.0 398	Temp. 73°.
340 350	.1824	.2411	.00 39	.00 41	.0 377	.0 396	.0 387	
330 800	.1788	.2373	.00 36	.00 38	.0 377	.0 398	.0 388	
320 400	.1750	.2336	.00 38	.00 37	.0 365	.0 356	.0 361	
311 200	.1714	.2301	.00 36	.00 35	.0 391	.0 380	.0 386	
300 500	.1672	.2257	.00 42	.00 44	.0 393	.0 411	.0 402	
290 400	.1633	.2214	.00 39	.00 43	.0 386	.0 426	.0 406	
281 600	.1605	.2180	.00 28	.00 34	.0 318	.0 387	.0 353	
270 100	.1568	.2135	.00 37	.00 45	.0 322	.0 391	.0 357	
260 700	.1536	.2101	.00 32	.00 34	.0 340	.0 362	.0 351	
250 200	.1496	.20 63	.00 40	.00 38	.0 381	.0 362	.0 372	
240 300	.1459	.20 26	.00 37	.00 37	.0 374	.0 374	.0 374	
231 000	.1427	.1992	.00 32	.00 34	.0 344	.0 366	.0 355	
220 500	.1387	.1952	.00 40	.00 40	.0 381	.0 381	.0 381	
211 800	.1352	.1914	.00 35	.00 38	.0 402	.0 437	.0 419	
200 100	.1310	.1872	.00 42	.00 42	.0 359	.0 359	.0 359	
190 600	.1274	.1833	.00 36	.00 39	.0 379	.0 410	.0 395	1:35 P.M.
180 100	.1232	.1792	.00 42	.00 41	.0 400	.0 390	.0 395	
170 000	.1193	.1750	.00 39	.00 42	.0 386	.0 416	.0 401	
160 350	.1167	.1711	.00 26	.00 39		.0 377		
150 200	.1142	.1674	.00 25	.00 37		.0 365		
140 900	.1119	.1638	.00 23	.00 36		.0 387		Temp. 74°.
130 600	.1129	.1591		.00 47				
120 300	.1041	.1545	.00 88	.00 46				

Roller adjusted on extensometer #1.

Test No. 6.

May 6, 1905.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
110100	.1010	.1504	.0031	.0041	.0304	.0402	.0353	Temp. 76°.
100000	.0985	.1464	.0025	.0040		.0396		
90800	.0951	.1427	.0034	.0037	.0370	.0402	.0386	
80900	.0915	.1387	.0036	.0040	.0364	.0404	.0384	
70500	.0873	.1346	.0042	.0041	.0403	.0394	.0399	
60000	.0831	.1306	.0042	.0040	.0400	.0382	.0391	
50100	.0794	.1265	.0037	.0041	.0374	.0414	.0394	
40400	.0762	.1224	.0032	.0041	.0330	.0422	.0376	
29650	.0719	.1182	.0043	.0042	.0400	.0391	.0395	
20700	.0688	.1146	.0031	.0036	.0346	.0402	.0374	
10250	.0650	.1104	.0038	.0042	.0364	.0402	.0383	
0	.0604	.1072	.0046	.0032	.0449	.0312	.0380	2:43 1/2 P.M.
250	.0619	.1085						5:01 P.M. Temp. 76°.

Test No. 7.

May 6, 1905.

(a) 250	.0642	.1106							8:11 P.M. Temp. 74°.
60250	.0870	.1337	.0228	.0231	.0380	.0385	.0383		3 min. interval
			.0375	.0388	.0376	.0389	.0383		
99900	.1017	.1494	.0147	.0157	.0371	.0396	.0384		
200600	.1396	.1881	.0379	.0387	.0376	.0384	.0380		
300500	.1757	.2270	.0361	.0389	.0361	.0389	.0375		
399500	.2113	.2655	.0356	.0385	.0360	.0389	.0375		8:53 P.M.
499500	.2482	.2992	.0369	.0337	.0369	.0337	.0353		
598000	.2864	.3322	.0382	.0330	.0388	.0335	.0362		
500600	.2522	.2957	.0342	.0365	.0351	.0375	.0363		

Test No. 7.

May 6, 1905.

Load lbs.	Reading		Increment		Per 100000 lbs.			Remarks
	#1	#2	#1	#2	#1	#2	Mean	
401400	.2143	.2578	.0379	.0379	.0382	.0382	.0382	
300300	.1758	.2188	.0385	.0390	.0381	.0386	.0384	
202800	.1390	.1808	.0360	.0380	.0369	.0390	.0380	
100500	.1006	.1408	.0384	.0400	.0375	.0391	.0383	
60900	.0860	.1255	.0146	.0153	.0369	.0387	.0378	
			.0377	.0394	.0375	.0392	.0384	
0	.0629	.1014	.0231	.0241	.0379	.0395	.0387	9:44 P.M.
Initial Load = 2000 lbs.								May 11, 1905.
(b) 0	.0016	.1707						8:45 P.M.
100900	.0363	.2113	.0347	.0406	.0344	.0402	.0373	Temp. 74°.
199500	.0730	.2504	.0367	.0391	.0372	.0397	.0385	
299700	.1107	.2891	.0377	.0387	.0376	.0386	.0381	3 min. interval
399700	.1486	.3282	.0389	.0391	.0389	.0391	.0390	
499400	.1846	.3667	.0360	.0385	.0361	.0386	.0374	
598500	.2237	.4052	.0391	.0385	.0394	.0388	.0391	9:22 P.M.
500700	.1831	.3677	.0406	.0375	.0415	.0383	.0399	
400900	.1535	.3290	.0296	.0387	.0296	.0387		
299800	.1153	.2894	.0382	.0396	.0378	.0392	.0385	
201000	.0784	.2506	.0369	.0388	.0373	.0393	.0383	
101000	.0410	.2108	.0374	.0398	.0374	.0398	.0386	
250	.0043	.1698	.0367	.0410	.0364	.0406	.0385	9:06 1/2 P.M.
Same as above with two rubber bands added at each spring. That on #1 weaker.								
(c) 300	.0019	.1705						Temp. 73°.
								10:41 P.M.
60000	.0230	.1945	.0211	.0240	.0354	.0402	.0377	
			.0354	.0400	.0355	.0401	.0378	
99950	.0373	.2105	.0143	.0160	.0358	.0400	.0379	

Test No. 8.

Test of Steel Bar. Diameter of bar = 3.42 inches. Area = 9.19 square inches.

Load lbs.	Deflection of Guide Columns					Remarks
	N.E. in.	N.W. in.	S.W. in.	S.E. in.	Ave. in.	
0	0.0	0.0	0.0	0.0		May 13, 1905, 3 P.M.
100000	(0.18N (.0 W	0.10N ,03W	0.08N .03E	0.10N .0 E	0.12N .0 E	Screws stretched 1/4 in. in 450,000 lbs.
200000	(0.18N (.03E	0.10N .0 E	0.10N .0 E	0.08N .0 E	0.12N .01E	
300000	(0.23N (.03E	0.13N .0 E	0.08N .05E	0.15N .03E	0.15N .02E	
400000	(0.28N (.05W	0.13N .05W	0.13N .05E	0.15N .0 E	0.17N .01W	
450000	(0.23N (0.07E	0.20N .05E	0.18N .05E	0.15N .0 E	0.19N .04E	

Maximum load = 460,000 lbs.
 Breaking load = 331,000 lbs.
 Weighing head jumped 1/8 inches.
 Diameter reduced to 2.13 inches.
 Elongation in 8 in. = 4.17 in.
 " " 2 " = 1.97 "

Unit load = 50,050 lbs. per
 square inch.
 Unit load = 36,100 lbs. per
 square inch.
 Area = 3.565 square inches.

Test No. 9.

Test of Cast Iron Bar.

Diameter of bar = 5.55 inches. Area = 24.19 square inches.

Breaking load = 485,000 lbs. Unit load = 20,950.

Guide columns moved north 0.05 inches.

Weighing head jumped 0.85 inches.

Pulling head did not come down over 1/16 in. below final position.

Specimen broke in shoulder.

Test No. 10.

Test of Eccentric Loading.

C.1. column 6 inches in diameter, $3/4$ inches thick, 14 feet $1/2$ inches long. Plane of column parallel with screws, 5 inches eccentricity, 2 $1/2$ inches at each end.

May 15, 1905.

4:30 P.M.

Load	Deflection of Guide Columns					Deflection of Top of Weighing Columns	
	N.W.	N.E.	S.E.	S.W.	Aver.	E & W	N & S
0	0.0	0.0	0.0	0.0		0.0	0.0
100000	(0.20S (0.03W	0.10S .03W	0.15S .03E	0.15S .03W	0.15S .02W	0.13N	0.25E
200000	(0.50S (.03W	0.43S .03W	0.45S .00E	0.45S .03W	0.46S .02W	0.25N	0.25E
300000	(0.73S (.03W	0.68S .03W	0.73S .03W	0.70S .03W	0.71S .03W	0.25N	0.25E

Test No. 11.

Same Eccentricity,
Rt. L^s to plane of screws.

0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100000	(0.00S (0.03E	0.03N .03E	0.05N .05E	0.05N .05E	0.03N .04E	0.00	0.25W
200000	(0.05N (.08E	0.03N .05E	0.08N .10E	0.10N .10E	0.07N .08E	0.13N	0.25W
300000	(0.08N (.15E	0.03N .15E	0.10N .18E	0.10N .15E	0.08N .16E	0.25N	0.50W
Column buckled on starting to release load.							

Test No. 12.

2-7" x 16" Creosoted Beams tied together by batten plates. 5 inches eccentricity, all at bottom. Plane of beams parallel to screws.
May 16, 1905. 2:00 P.M. Length of column = 14 feet no inches.

0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100000	(0.25S (.08E	0.23S .08E	0.20S .08E	0.25S .08E	0.23S .08E	0.13N	0.0

Test No. 12 - continued.

Load	Deflection of Guide Columns					Deflection of Top of Weigh. Columns	
	N.W.	N.E.	S.E.	S.W.	Aver.	E & W	N & S
200000	(0.43S (.10 E	0.43S .13E	0.43S .08E	0.45S .10 E	0.44S .10 E	0.25N	0.0
300000	(0.73S (.10 E	0.65S .13E	0.65S .08E	0.73S .10 E	0.69S .10 E	0.31N	0.06W
400000	(0.80S (.13E	0.83S .15E	0.83S .05E	0.85S .08E	0.83S .10 E	0.38N	0.06W.
Weighing column on S.W. corner came up against pulling head. Clearance only 0.50 inches at best.							

Test No. 13.

Test of Eccentric Loading, same as before except that eccentricity is divided between top and bottom. Beams at right angles to plane of screws. May 16, 1905.

Load lbs.	Deflections Guide Columns					Weighing Columns	
	N.W. in.	N.E. in.	S.E. in.	S.W. in.	Aver. in.	E & W in.	N & S in.
0	0.0	0.0	0.0	0.0		0.0	0.0
100000	(0.10N (.03E	0.10N .00E	0.10N .03E	0.10N .03E	0.10N .02E	0.0	0.0
200000	(0.15N (.05E	0.15N .08E	0.15N .08E	0.13N .08E	0.15N .07E	0.06N	0.0
300000	(0.15N (.10E	0.10N .13E	0.23N .13E	0.13N .15E	0.15N .13E	0.06N	0.0
400000	(0.15N (.18E	0.05N .15E	0.05N .18E	0.08N .18E	0.08N .17E	0.13N	0.0
500000	(0.20N (.25E	0.00N .25E	0.03N .28E	0.08N .33E	0.04N .28E	0.19N	0.0

Column started to buckle a little before 500,000 lb. was reached in a plane parallel to plane of screws.

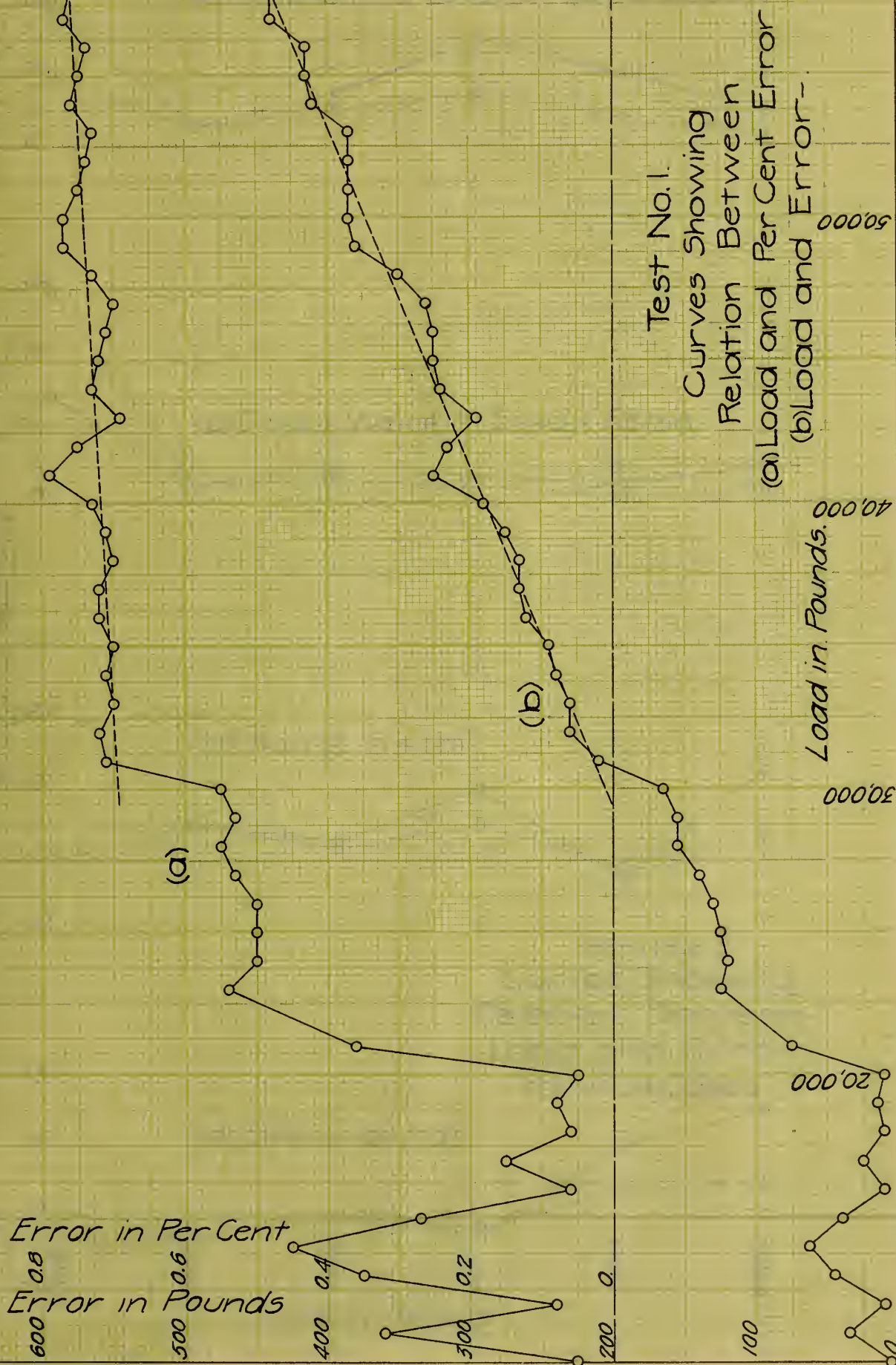
Test No. 14.

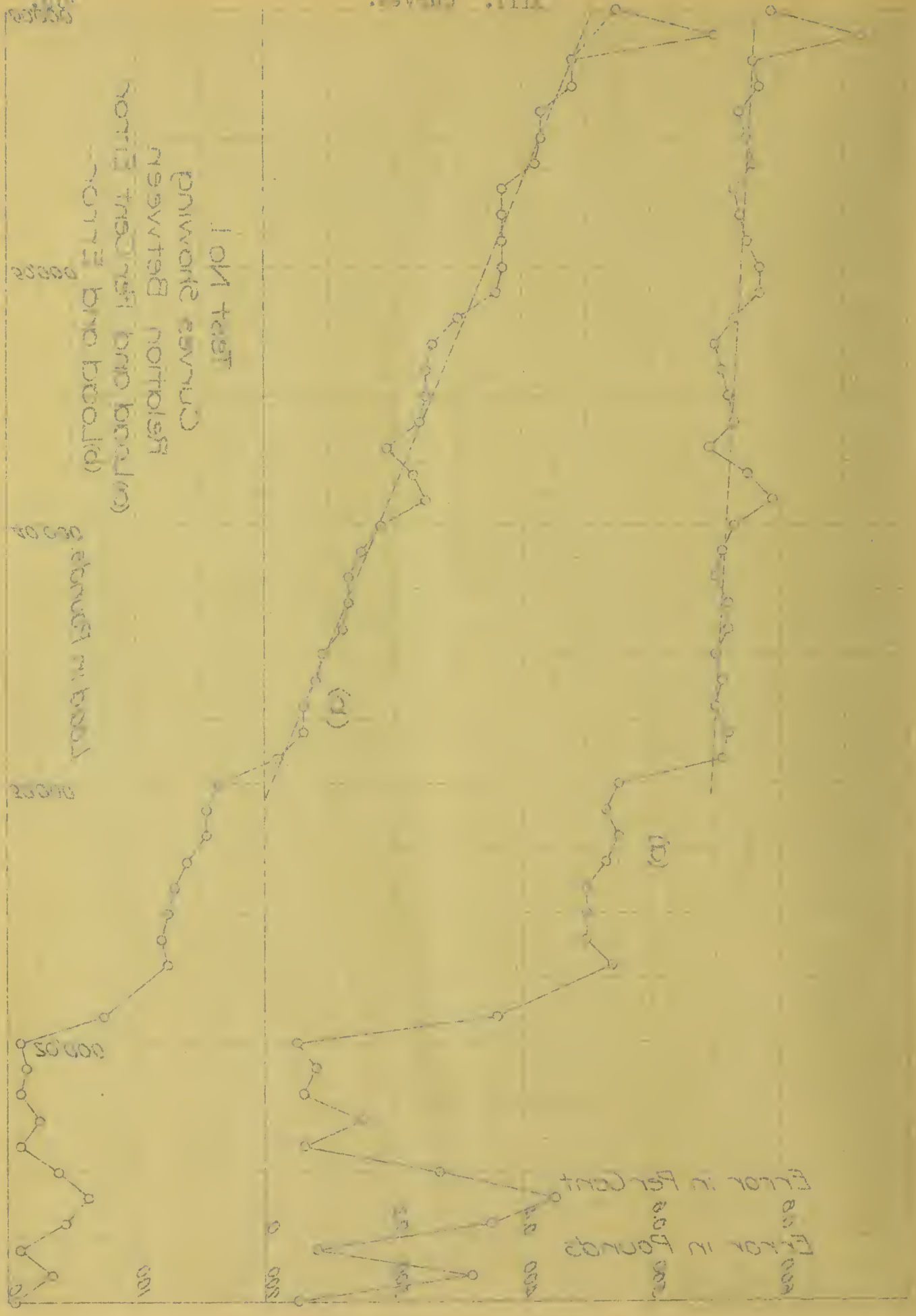
Test of Power Used.

*Speed	lbs. Load	Watts		Watts Total	H.P.
		Line A	Line B		
0.4	0	220	80	300	1.60
	100,000	280	130	410	2.20
	200,000	340	180	520	2.80
	300,000	380	240	620	3.32
	400,000	420	260	680	3.64
1.0	400,000	640	500	1140	6.12
2.0	400,000	960	840	1800	9.64
Running head up		500	280	780	4.20

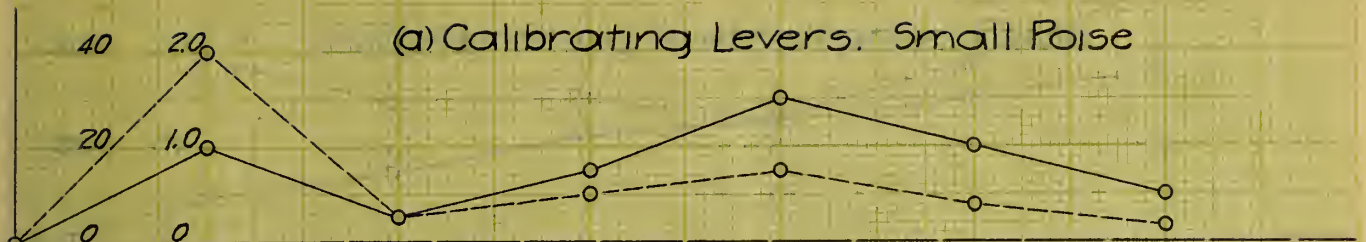
* inches per minute.

Note:- Reducer of four was used, hence total watts is multiplied by four to get final horse power. Observations were taken during test number 12.

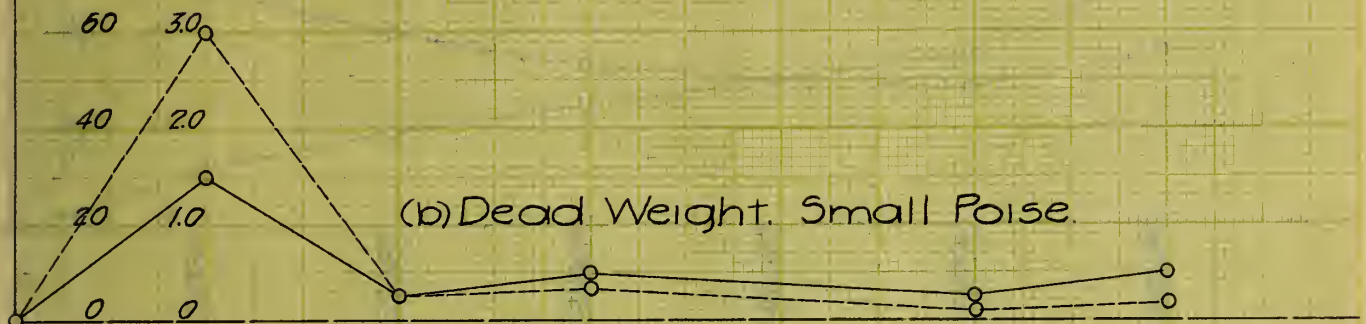




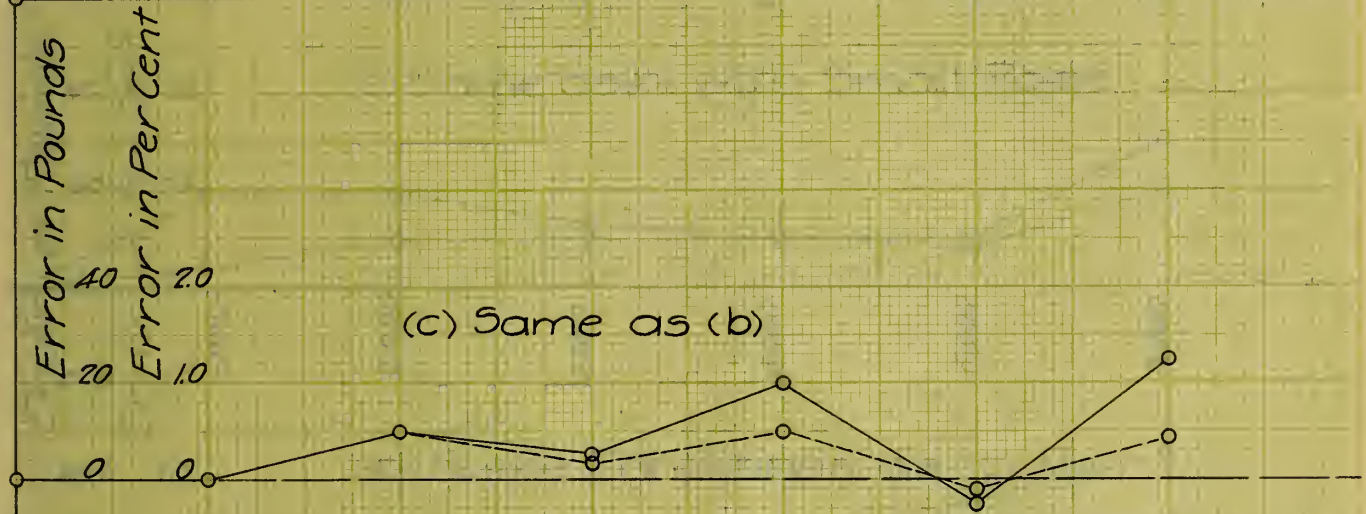
(a) Calibrating Levers. Small Poise



(b) Dead Weight. Small Poise

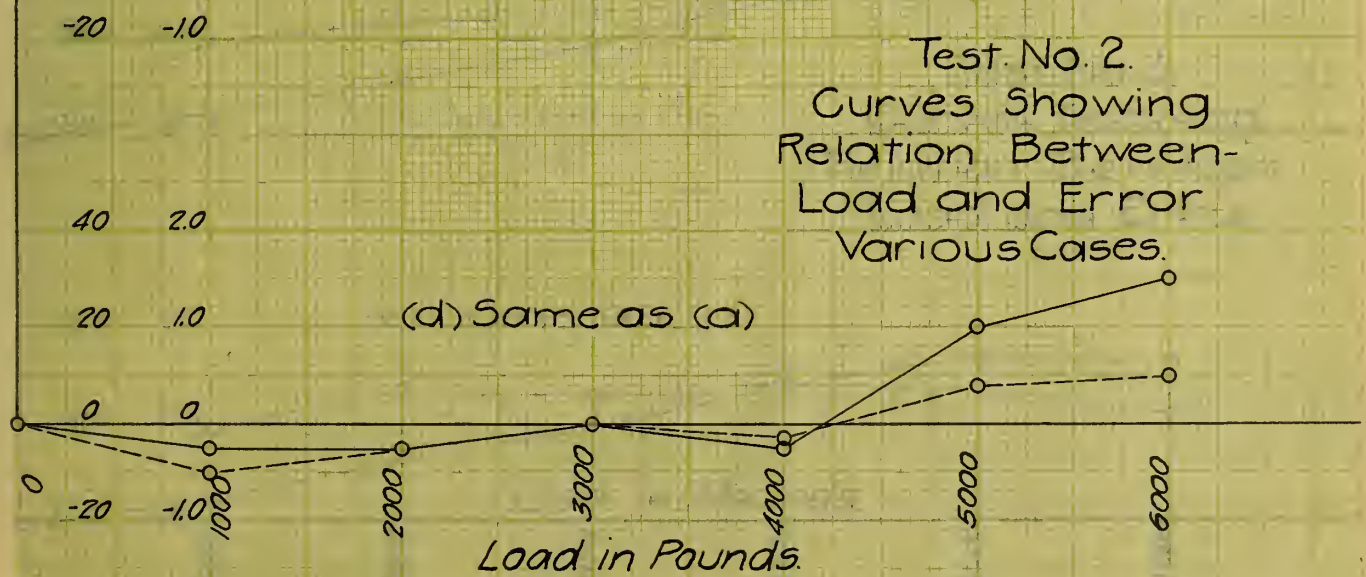


(c) Same as (b)



Test No. 2.
Curves Showing
Relation Between-
Load and Error
Various Cases.

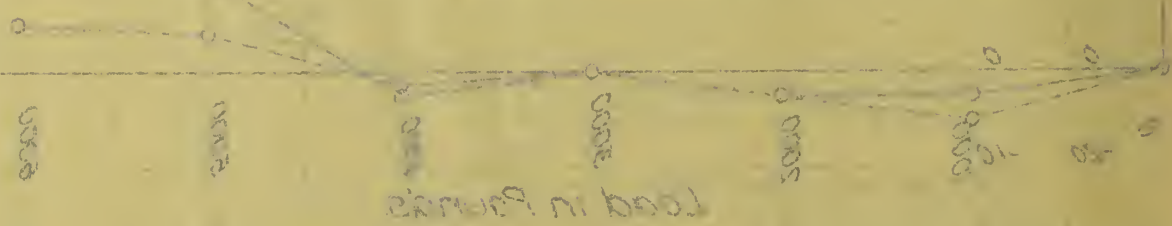
(d) Same as (a)



Load in Pounds.

Test No. 2
Curves showing
Relation Between
Load and Error
Various Cases.

(a) Same as (c)



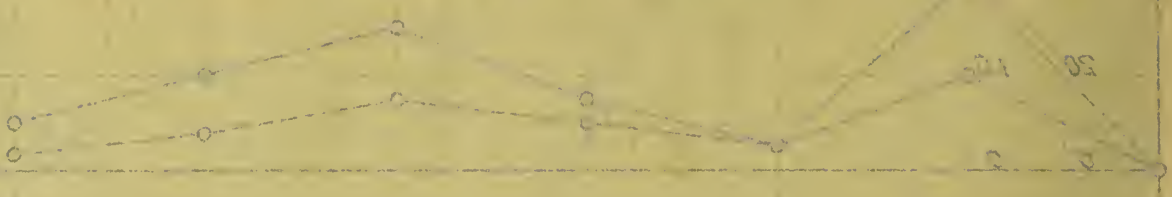
(c) Same as (b)

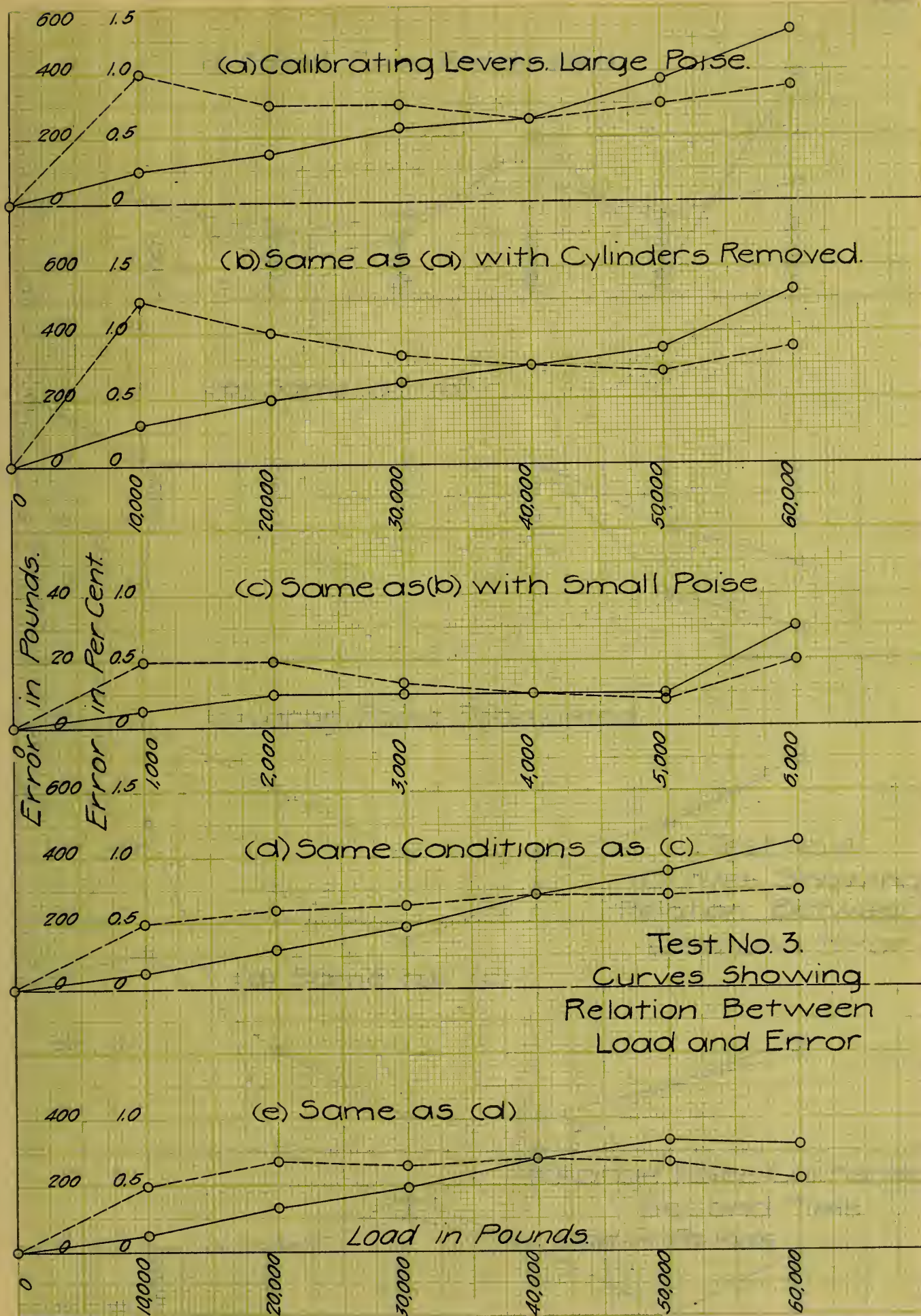


(b) Dead weight Small Paise

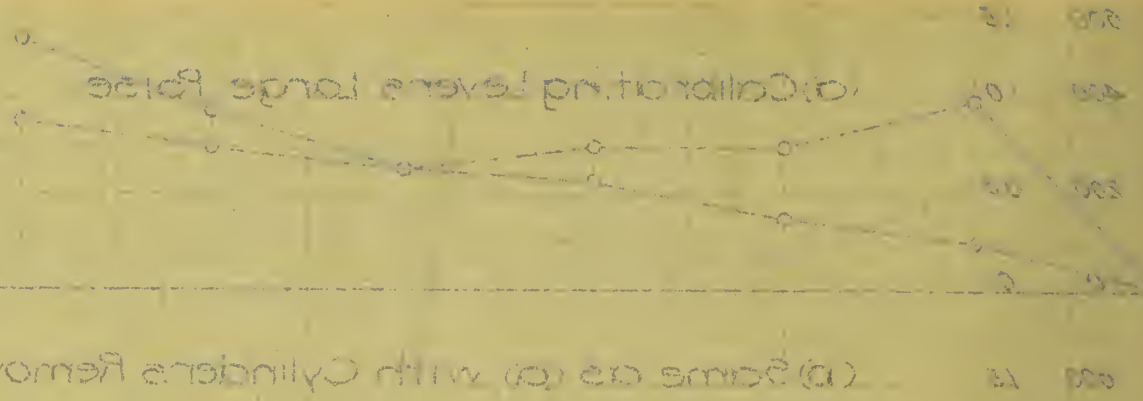
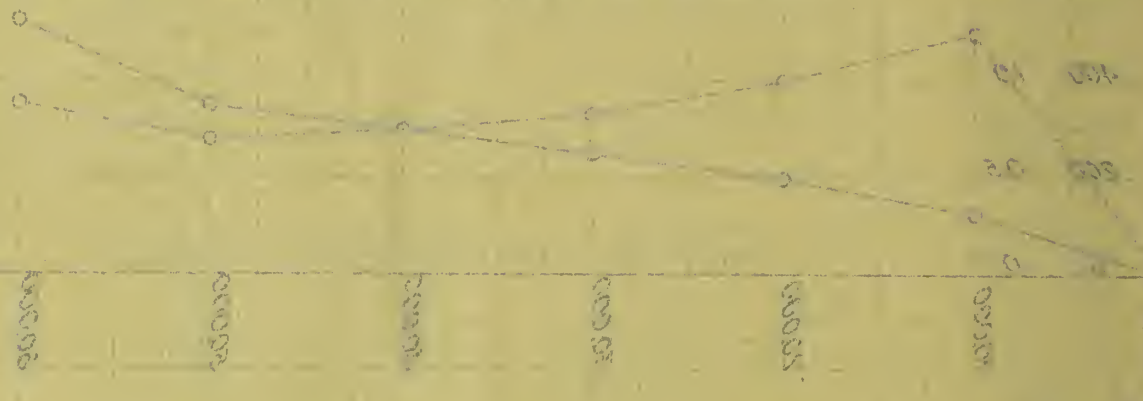
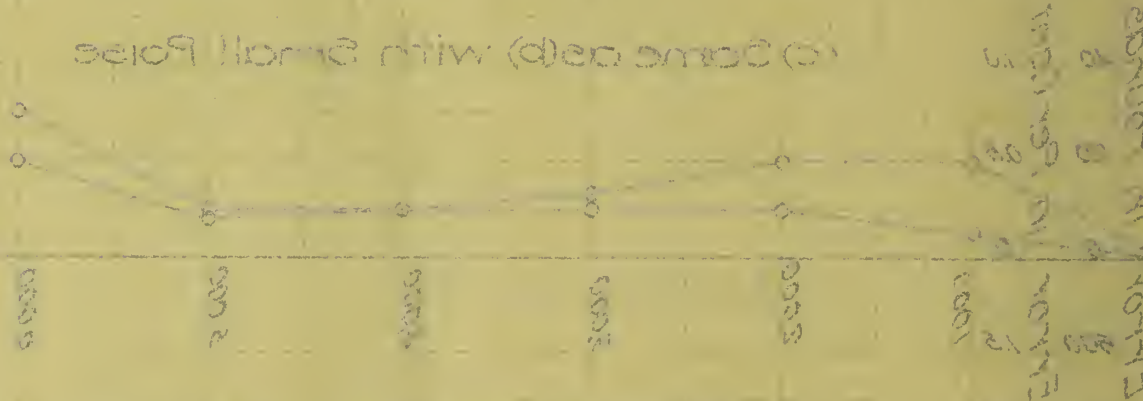
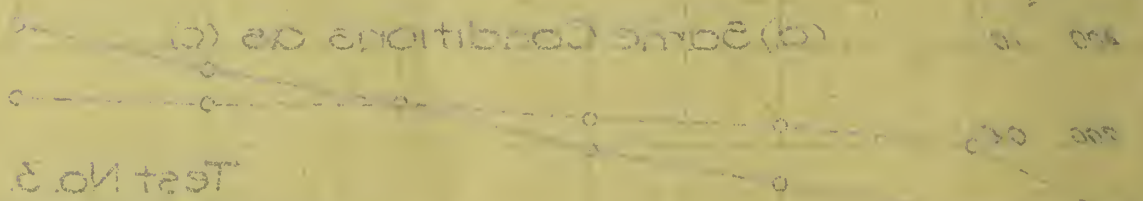
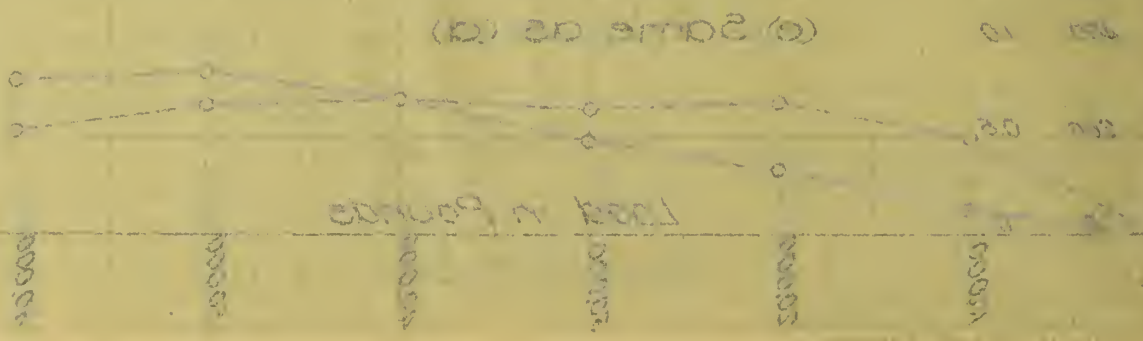


(a) Calibrating Levers. Small Paise

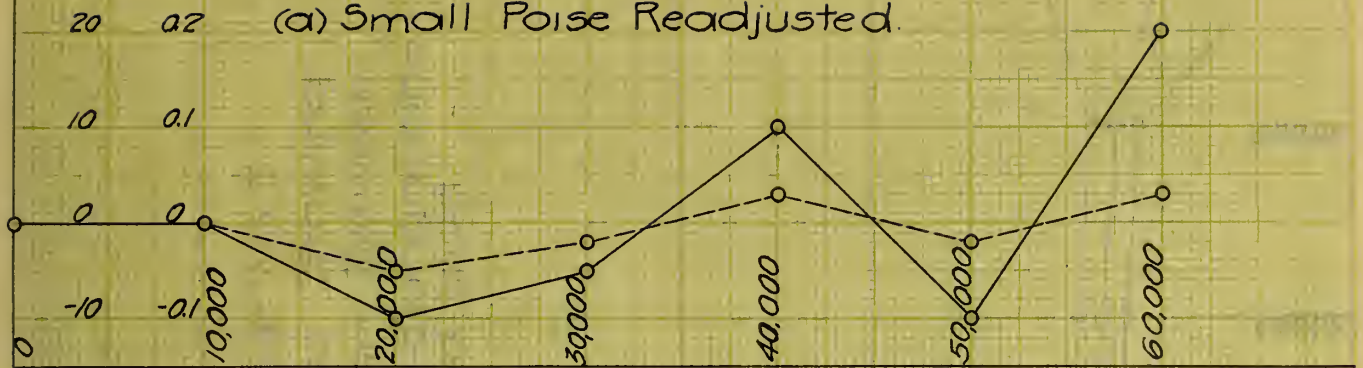




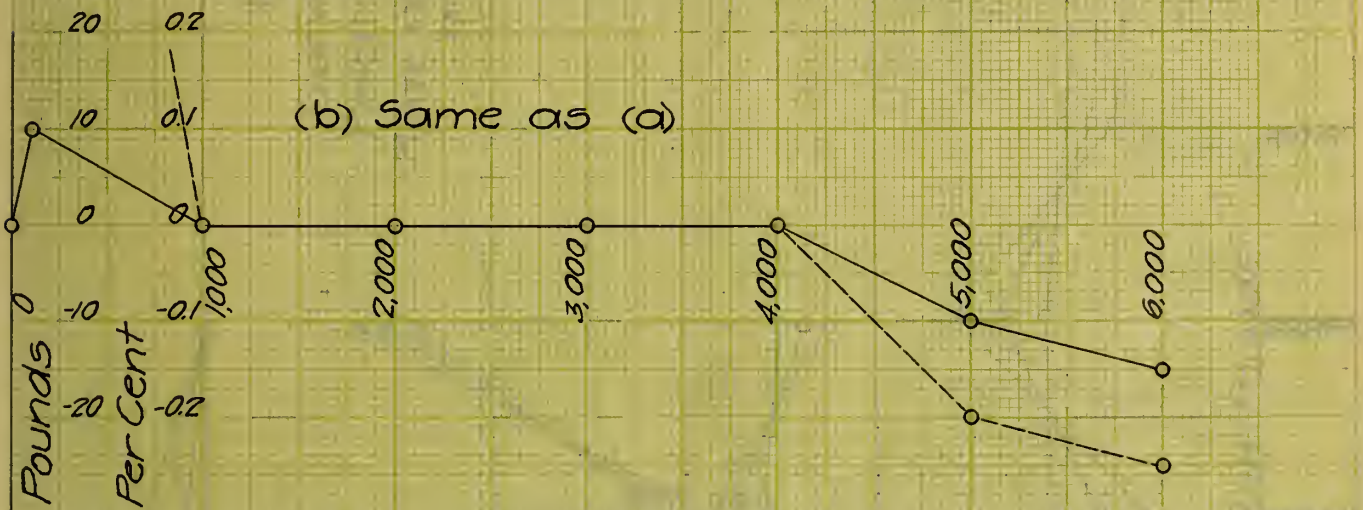
Load and Error Relation Between Curves showing Test No. 3



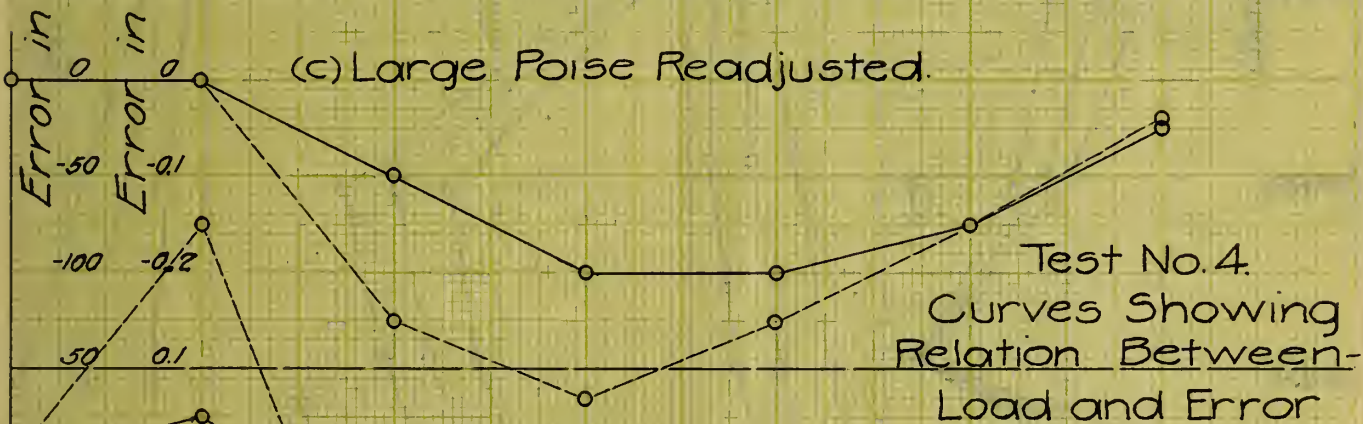
(a) Small Poise Readjusted.



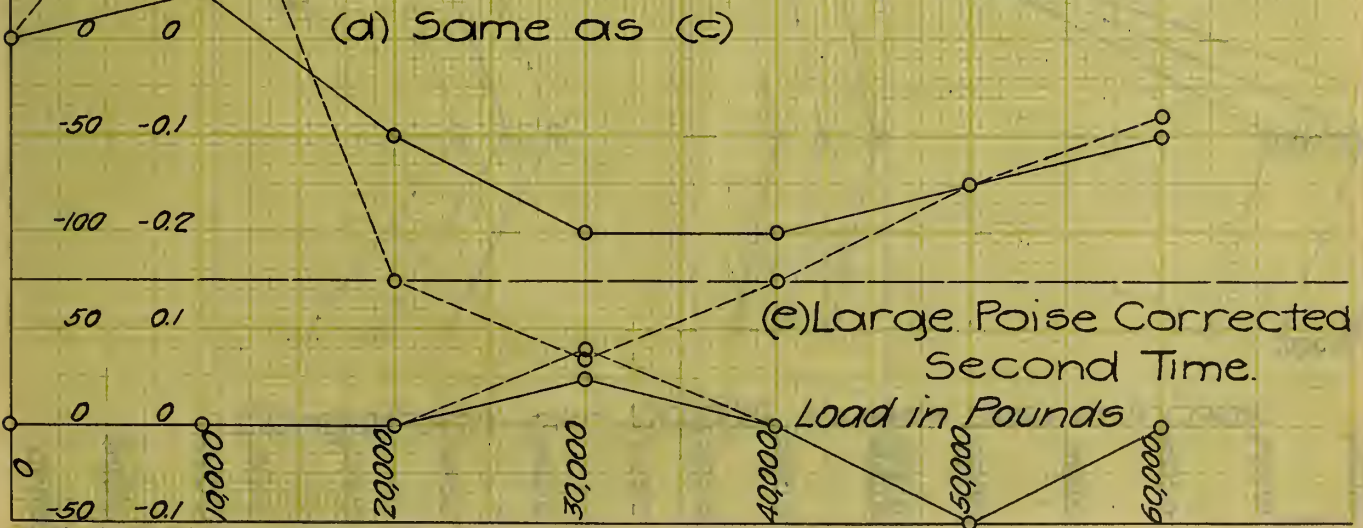
(b) Same as (a)



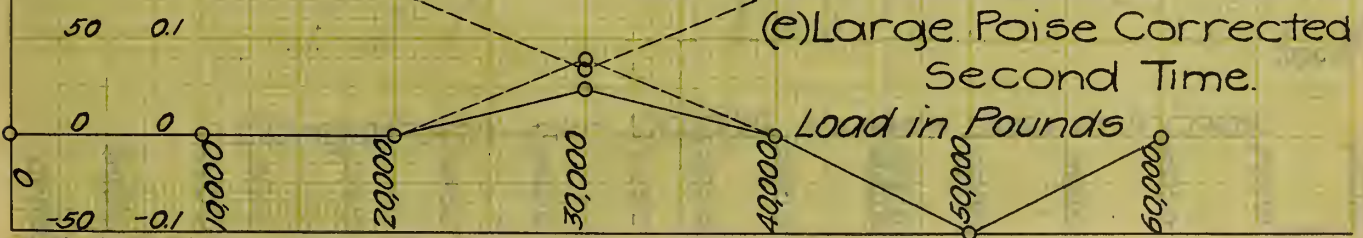
(c) Large Poise Readjusted.



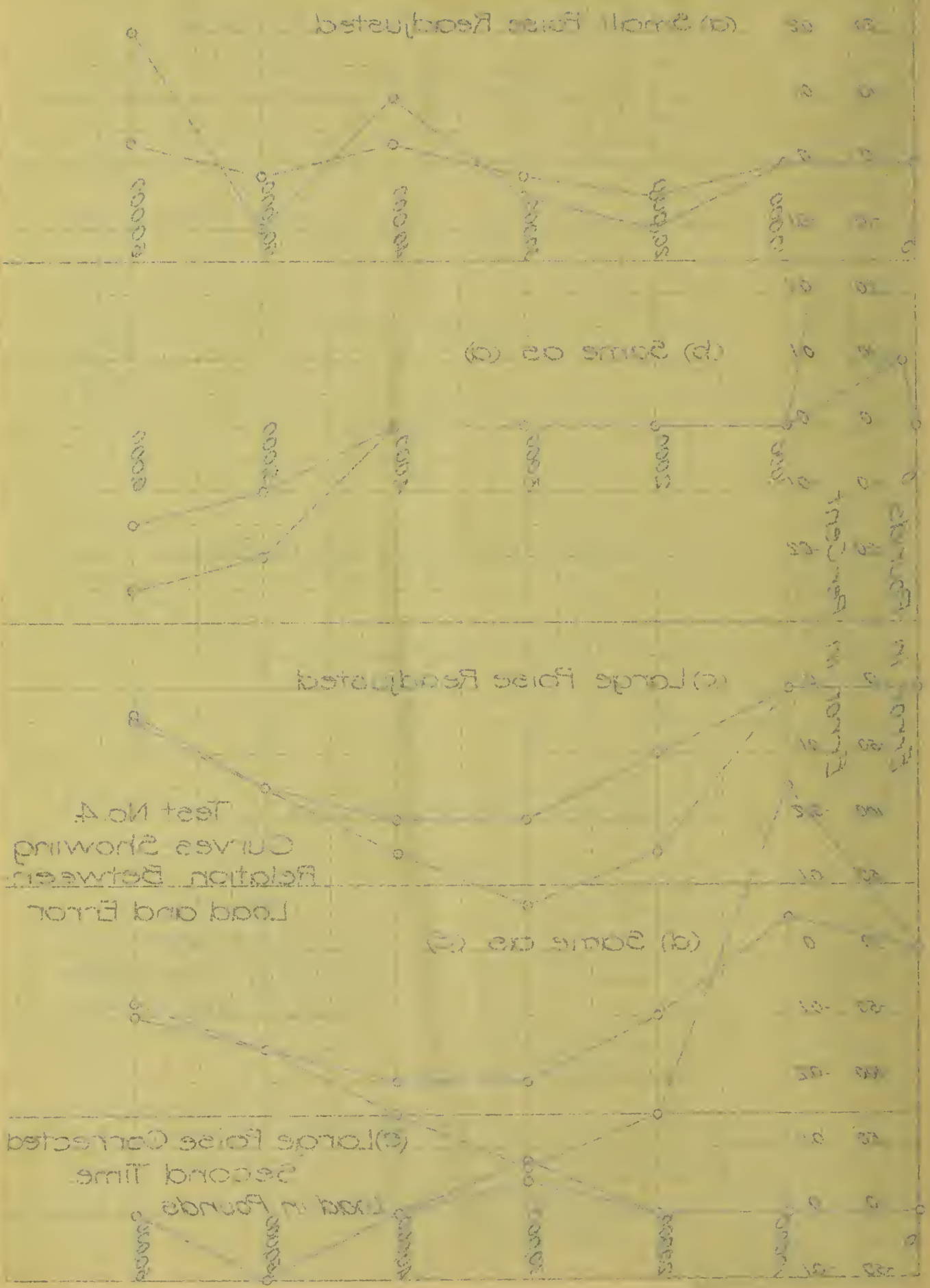
(d) Same as (c)



(e) Large Poise Corrected Second Time.

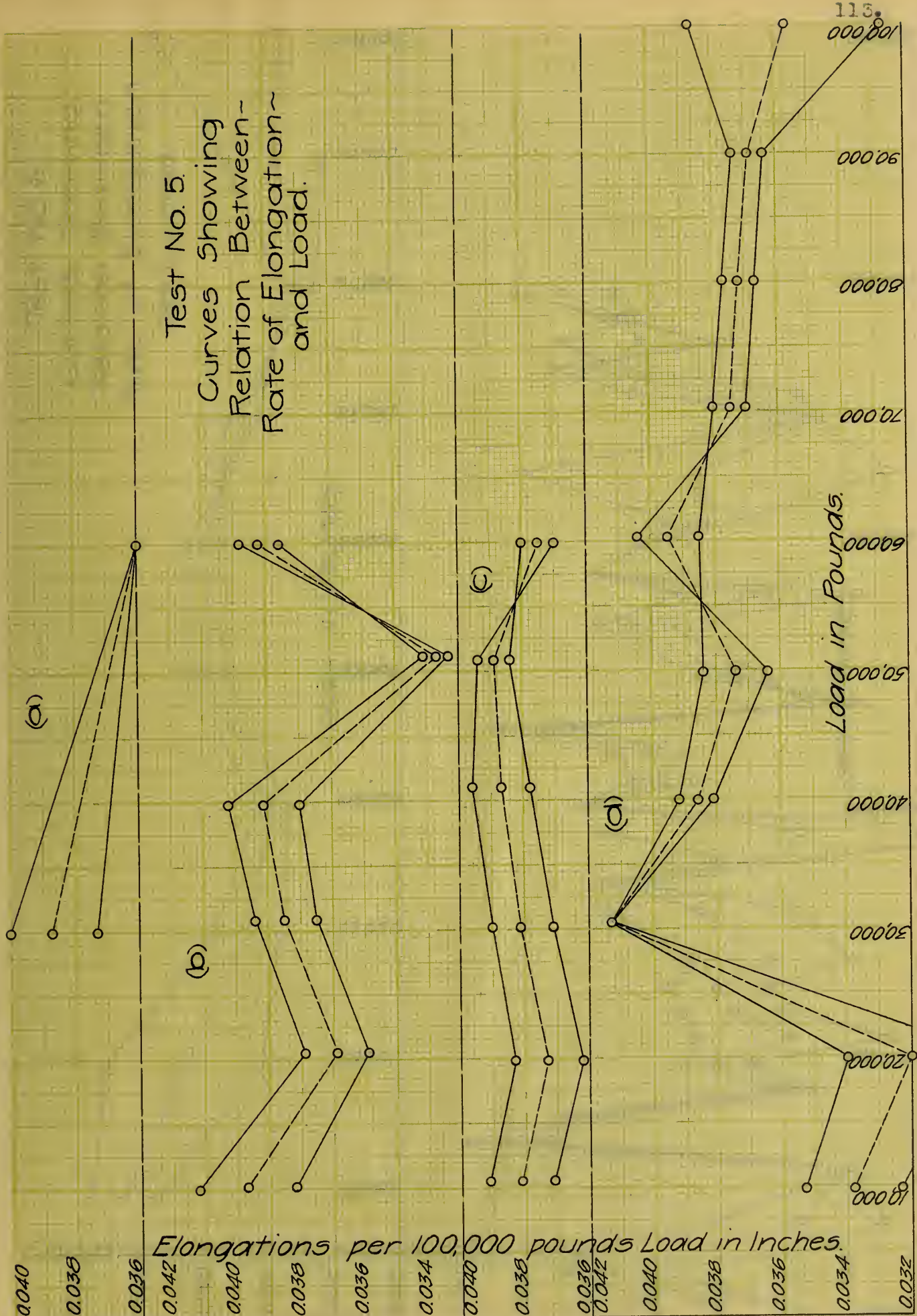


Test No. 4
Curves Showing
Relation Between
Load and Error

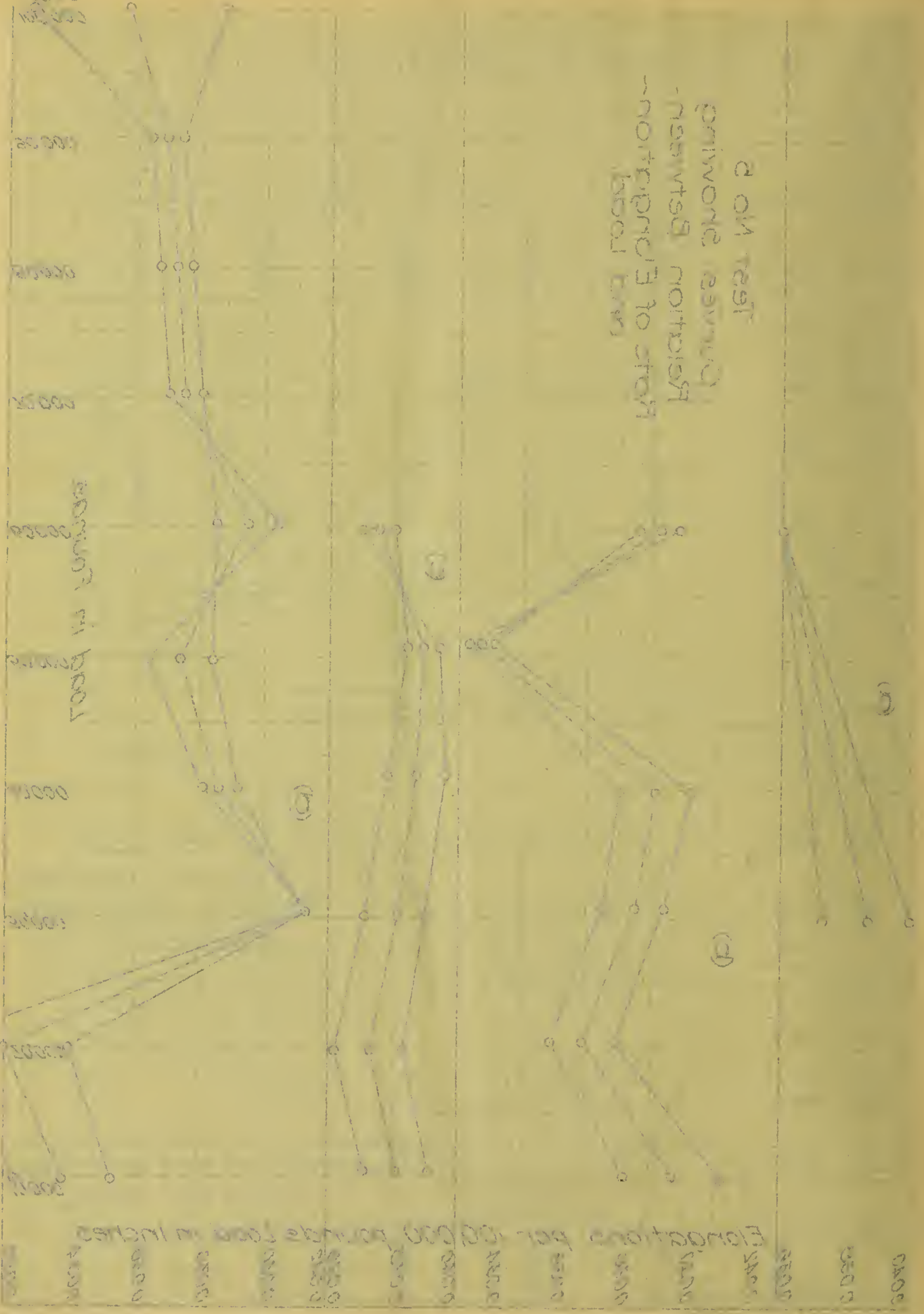


Test No. 5.

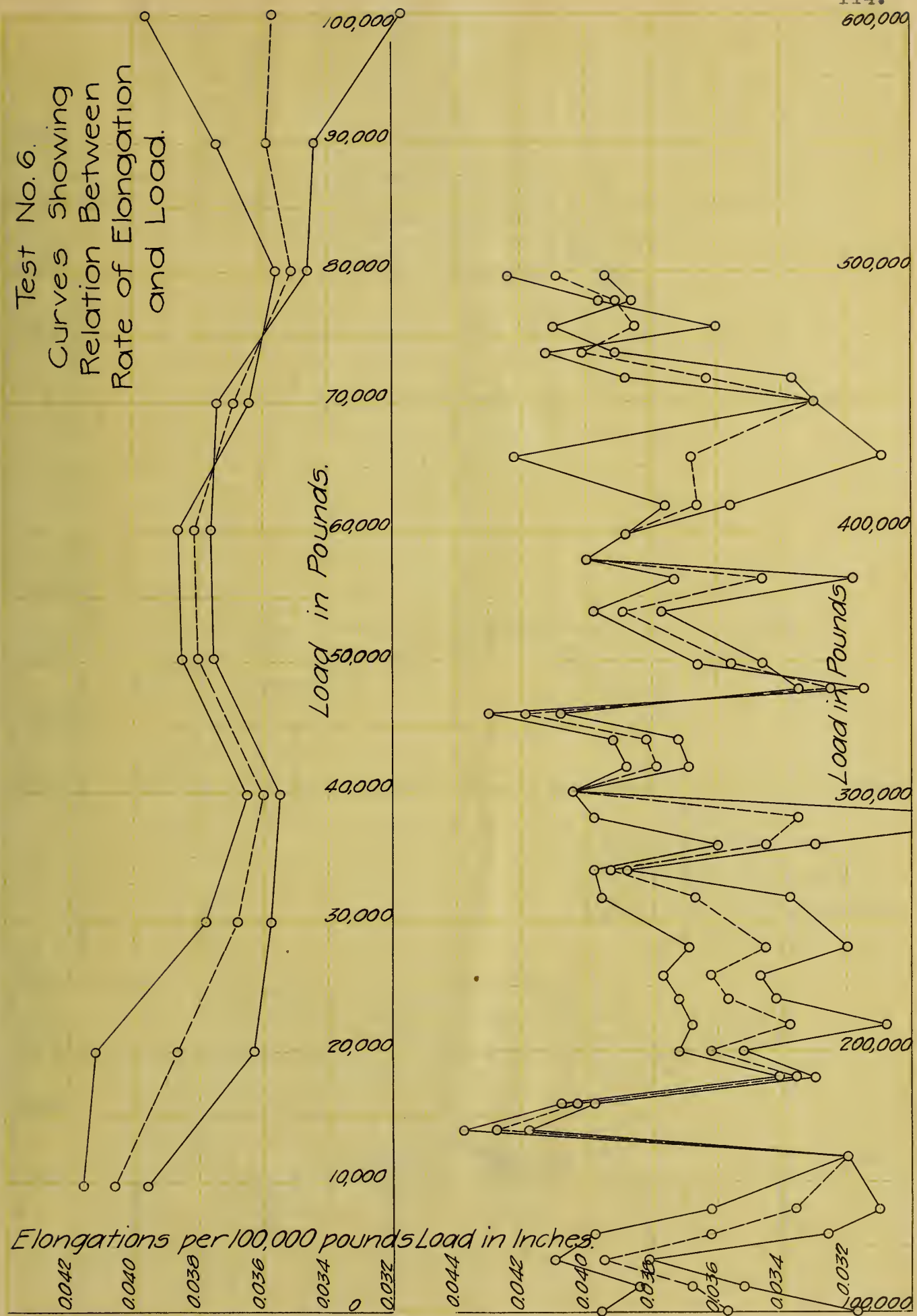
Curves Showing
Relation Between~
Rate of Elongation~
and Load.

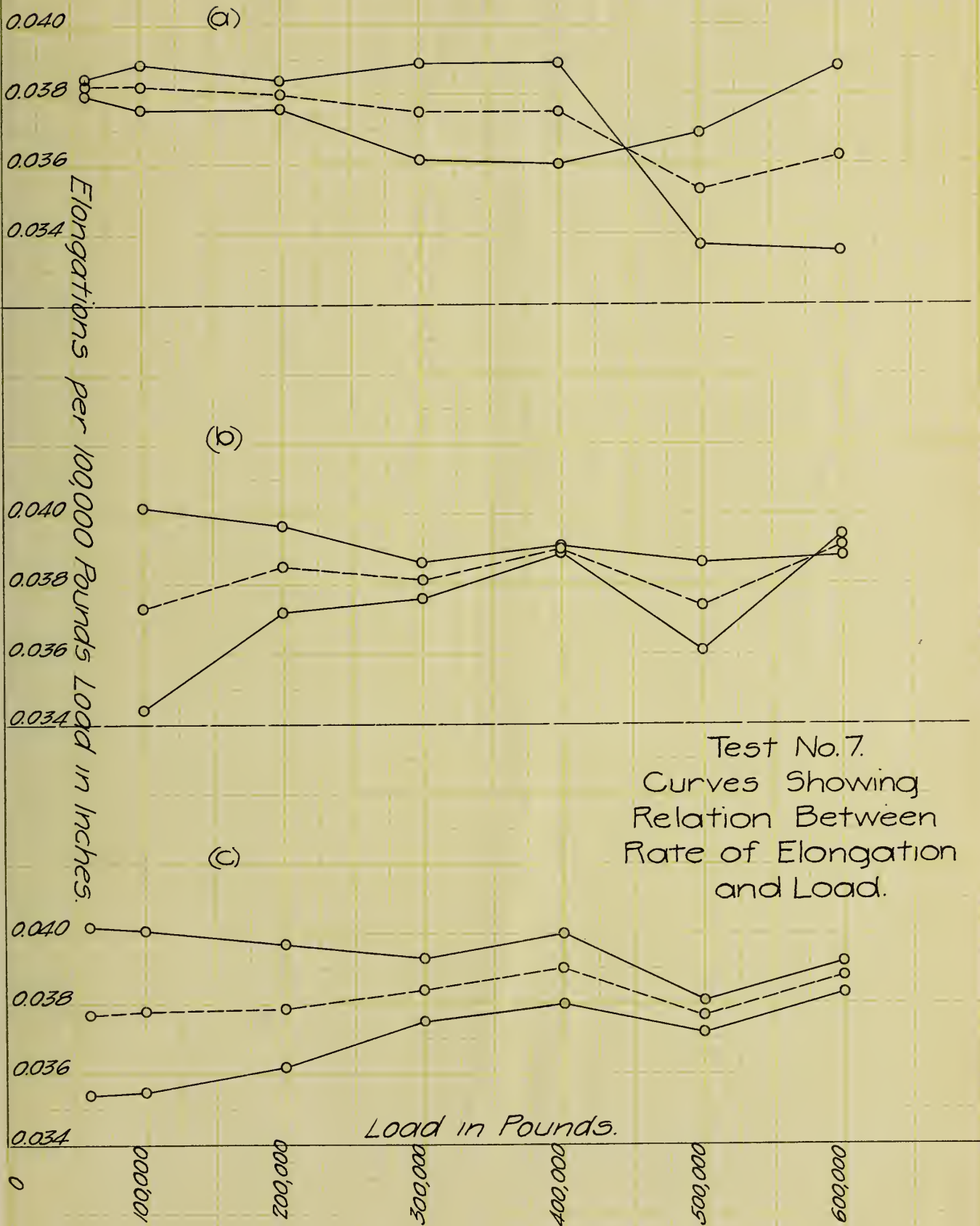


2011 test
 - private security
 - private security
 - private security
 - private security



Test No. 6.
Curves Showing
Relation Between
Rate of Elongation
and Load.

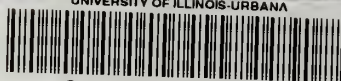








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